WASP8 Multiple Algae - Model Theory and User's Guide

Supplement to Water Quality Analysis Simulation Program (WASP) User Documentation

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NOTICE

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Contents

1 Introduction

Planktonic algae are important components of water quality models for several reasons, including (Bowie et al. 1985):

- Algal dynamics and nutrient dynamics are closely linked together since nutrient uptake during algal growth is the main process which removes dissolved nutrients from the water, and algal respiration and decay are major components of nutrient recycling.
- Algal processes can cause diurnal variations in dissolved oxygen due to photosynthetic oxygen production during the daylight combined with oxygen consumption due to algal respiration during the night. Seasonal oxygen dynamics may also be closely tied to algal dynamics, particularly in highly productive stratified systems, since the respiration and decomposition of algae which settles below the photic zone is often a major source of oxygen depletion.
- Algae can affect pH through the uptake of dissolved CO_2 during photosynthesis and the recycling of CO_2 during respiration.
- Algae are the dominant component of the primary producers in many systems, particularly in lakes and estuaries. Since they form the base of the food chain, they play a major role in the dynamics of all successive trophic levels.
- Suspended algae are often a major component of turbidity.
- Algal blooms can restrict recreational uses of water, sometimes resulting in fish kills under severe conditions.
- Algae can cause taste and odor problems in water supplies, and filter clogging problems at water treatment facilities.

Planktonic algae are also commonly referred to as phytoplankton, from the Greek phyton or "plant" and planktos meaning wanderer or drifter. The term phytoplankton is usually taken to refer to all planktonic photoautotrophic microorganisms. While the importance of planktonic algae, or phytoplankton, is well established, it must be recognized that phytoplankton consist of a diverse assemblage of nearly all major taxonomic groups (Wetzel 2001). That diversity may be illustrated using the taxonomic classification of major phytoplankton groups (Figure 1) in comparison to plants and animals. Phytoplankton are not true plants and common groupings of phytoplankton (diatoms, green algae, etc.) actually represent separate phyla of the Kingdom Protista, each including a large diversity of organisms. For example, the Phylum Chlorophyta (green algae) includes approximately 16,000 species, the majority of which occur in fresh water. Blue-green algae are a common cause of water quality problems. However, blue-green algae are not an alga but are in a separate Domain and Kingdom (the bacteria) and are also known as cyanobacteria.

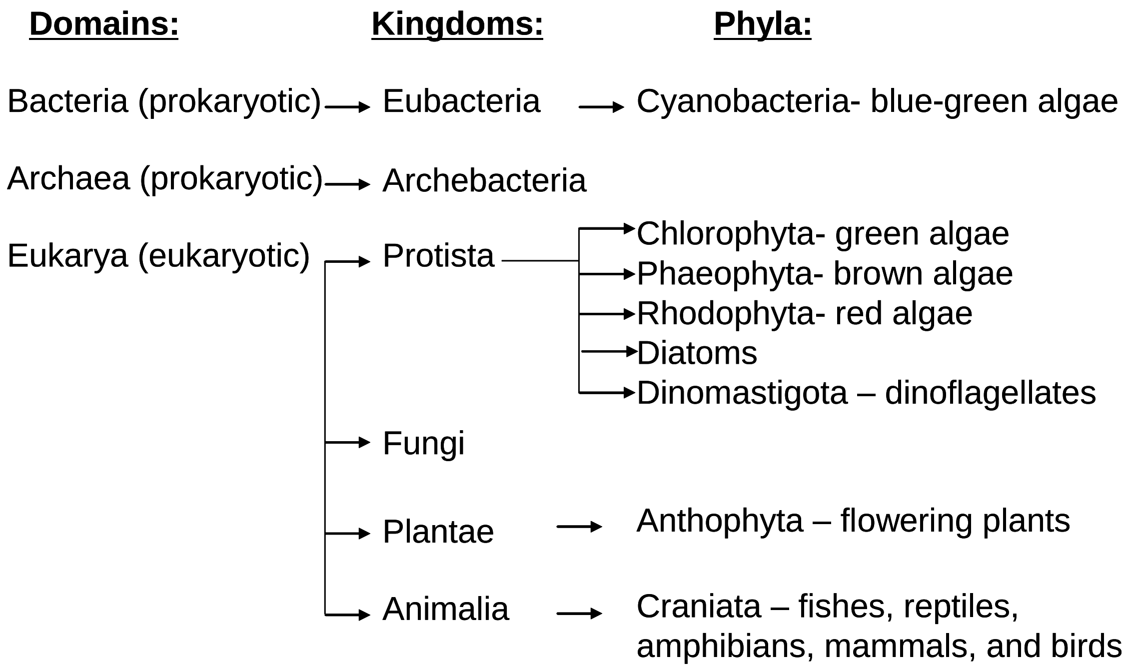

Figure 1. Taxonomic classification of major phytoplankton groups in comparison to other groups.

Although phytoplankton represent a very diverse assemblage of organisms, each functional group shares sufficient characteristics that a lumped approach is often used in water quality modeling. Two general approaches have been used to simulate algae in water quality models (Bowie et al. 1985):

1) Aggregating all algae into a single constituent (for example, total algae or chlorophyll a), or
2) Aggregating the algae into a few dominant functional groups (for example, green algae, diatoms, blue-greens, dinoflagellates, etc.).

The first approach is that used in previous versions of the WASP model, through Version 7.2. It is appropriate where the major focus is on short term simulations (days to weeks) where the primary interest is the effects of planktonic algae on general water quality parameters such as dissolved oxygen, nutrients, and turbidity. However, models of lakes, reservoirs, and estuaries focusing on longer-term simulations where seasonal variations are important often need the capabilities provided by the second approach. It is often important to distinguish differences between algal groups in order to realistically model both nutrient dynamics and phytoplankton dynamics, and to predict the occurrence of specific problems such as blue-green algal blooms.

This report summarizes approaches used in the modeling multiple algal groups as implemented in the Water Analysis and Simulation Program (WASP) resulting in the Multi-Class Phytoplankton Model (MPM). The WASP model was modified to include the capability of simulating three algal classes (e.g., diatoms, greens and blue greens). Because in particular diatoms are often limited by the availability of silica, which were not included in the previous WASP model, the model was also modified to include organic (particulate and dissolved) and inorganic dissolved silica as state variables. Since the algorithms added for the three algal groups were generic in structure (not specific to a particular algal group), algorithms for all algal groups included the impacts of fixation of atmospheric nitrogen, so the selection of which state variable represents which group is up to the user. The development of the WASP multi-algal routines was based on the review of five models which have the capability of simulating multiple algal groups:

- Multi-Class Phytoplankton Model (Bierman et al. 1980)
- FLWASP (AScI 1995)
- LAKE2K (Chapra and Martin 2004)
- CE-QUAL-W2 (Cole and Wells 2006), and
- CE-QUAL-ICM (Tilman et al. 2004)

Based, in part, upon the review of available models, the specific algorithms for the WASP model were developed and implemented. The modified WASP, or MPM, includes the following state variables:

Table 1. MPM State Variables

State Variable	Description
1	Ammonia Nitrogen (mg-N/L)
2	Nitrate Nitrogen (mg-N/L)
3	Dissolved Organic Nitrogen (mg-N/L)
4	Inorganic Phosphate (mg-P/L)
5	Dissolved Organic Phosphorus (mg-P/L)
6	Inorganic Silica (mg-Si/L)
7	Dissolved Organic Silica (mg-Si/L)
8	CBOD1 (ultimate) (mg-O2/L)
9	CBOD2 (ultimate) (mg-O2/L)

10	CBOD3 (ultimate) (mg-O2/L)
11	Dissolved Oxygen (mg/L)
12	Detrital Carbon (mg-C/L)
13	Detrital Nitrogen (mg-N/L)
14	Detrital Phosphorus (mg-P/L)
15	Detrital Silica (mg-Si/L)
16	Total Detritus (mg-DW/L)
17	Salinity (ppt)
18	Benthic Algae (g-DW/m2)
19	Periphyton Cell Quota Nitrogen (mg-N/gDW)
20	Periphyton Cell Quota Phosphorous (mg-P/gDW)
21	Inorganic Solids 1 (mg-DW/L)
22	Inorganic Solids 2 (mg-DW/L)
23	Inorganic Solids 3 (mg-DW/L)
24	Phytoplankton 1 (ug-Chla/L)
25	Phytoplankton 2 (ug-Chla/L)
26	Phytoplankton 3 (ug-Chla/L)

However, the model is structured to allow addition of more than the three specified algal groups, should it be necessary in future model applications.

2 Overview of MPM Eutrophication Kinetics and Model Constants

In this section, relevant kinetic formulations are presented. The presentation will concentrate on issues related to the algal and silica kinetics and the relationship between those kinetic processes and other modeling variables. A presentation of other processes included in the WASP model and their implementation can be found in the general WASP user's manual (Wool et al. 2006).

2.1 Biomass Units and Stoichiometry

Assumptions are necessary regarding the units of the algal state variables and the stoichiometric relationships between algal kinetic processes and those resulting in the production or consumption of other state variables, such as carbon, nitrogen, silica and phosphorus. As with previous versions of WASP, the input units for all algal groups are μg-Chl_a/L which are converted to internal model units of gC/m^3 based upon a C/Chl_a (C=Carbon, Chl_a=Chlorophyll-

a) stoichiometric ratio input by the user for each algal group. Additional inputs include stoichiometric ratios for Si/C, N/C, P/C and D/C (Si=Silica, N=Nitrogen, P=Phosphorus, and D=detritus). As tabulated below, stoichiometric constants may be varied between the algal groups.

Table 2. MPM Stoichiometric Constants for Phytoplankton Group i (i=1 to 3)

Phytoplankton Detritus to Carbon Ratio for Group i (mg D/mg C)
Phytoplankton Nitrogen to Carbon Ratio for Group i (mg N/mg C)
Phytoplankton Phosphorus to Carbon Ratio for Group i (mg P/mg C)
Phytoplankton Silica to Carbon Ratio for Group i (mg Si/mg C)
Phytoplankton Carbon to Chlorophyll Ratio for Group i (mg C/mg Chl)

2.2 *Phytoplankton Kinetics*

For all phytoplankton groups, sources and sinks of algae (S_k) are computed by difference between the growth rate of phytoplankton and their death and settling rates as:

$$S_{kj} = (G_{pj} - D_{pj} - k_{sj}) P_j$$

Equation 1

where:

Skj = reaction term for algal group i, mg carbon/L-day

Pj = phytoplankton population i, mg carbon/L

Gpj = growth rate constant, day^{-1}

Dpj = death plus respiration rate constant, day^{-1}

ksj = settling rate constant, day^{-1}

i = phytoplankton type

Note that the source and sinks will also vary between model segments.

2.2.1 Phytoplankton Growth

The specific growth rate, G_{Pj}, for algal group j is related to k_{ci}, the maximum 20EC growth rate at optimum light and nutrients, via the following equation.

$$G_{Pij} = k_{ic} X_{RT_{ij}} X_{RI_{ij}} X_{RN_{ij}}$$

Equation 2

where:

X_{RTij} = the temperature adjustment factor, dimensionless

X_{RIij} = the light limitation factor, dimensionless

X_{RNij} = the nutrient limitation factor as a function of dissolved inorganic phosphorus, nitrogen (DIP and DIN), and available silica, dimensionless

2.2.2 Temperature

Water temperature directly affects the phytoplankton growth rate. The selected maximum growth rate is temperature-corrected using temporally- and spatially-variable water column temperatures. Two alternative temperature correction formulations are included. The first is a theta model where the temperature correction is computed using:

$$X_{RT_{ij}} = \Theta_{ic}^{T-20}$$

Equation 3

where:

Θ_{ic} = temperature coefficient for algal group i, unitless

T = ambient water temperature, EC

and the theta coefficient is allowed to vary among algal groups. The theta method is used in previous versions of the WASP model for temperature adjusting essentially all kinetic rates. A limitation of the theta model is that it produces rate values that continually increase with temperature ("the more the better"), as opposed to other alternative formulations which allow for predicted rates to decrease both above and below an optimal value. An alternative formulation provided in the MPM model is (Cerco and Cole 1994),

$$X_{RTi} = k_{gp,opt} e^{-\kappa_1 (T - T_{opt})^2} \qquad T \le T_{opt}$$

Equation 4

$$X_{RTi} = k_{gp,opt} e^{-\kappa_2 (T - T_{opt})^2} \qquad T > T_{opt}$$

Equation 5

where T_{opt} is the optimal temperature; κ_1 and κ_2 are parameters that determine the shape of the relationship of growth to temperature below and above the optimal temperature, respectively. CE-QUAL-ICM and Lake2K use the same formulation.

In the MPM model, the default temperature correction is the theta model and is used where the user inputs a value of theta greater than one. Otherwise, if inputs are provided, the inhibition model is used or the rate of growth is not modified by temperature. The input constants are provided below:

Table 3. MPM temperature constants for Phytoplankton group i (i=1 to 3)

Phytoplankton Growth Temperature Coefficient for Group i
Optimal Temperature for Growth for Group i (°C)
Shape parameter for below optimal temperatures for Group i
Shape parameter for above optimal temperatures for Group i

2.2.3 Light

The MPM model incorporates the framework developed by Di Toro (1971) and by Smith (1980), extending upon a light curve analysis by Steele (1962), for formulating the impact of light on phytoplankton growth. The formulations account for both supersaturating light intensities and light attenuation through the water column. The instantaneous depth-averaged growth rate reduction developed by Di Toro is presented below and is obtained by integrating the specific growth rate over depth:

$$\overline{X_{RI}} = \frac{e\,f}{K_e\,D}\left[\exp\left\{-\frac{I_a}{I_{si}}\exp\left(-K_e\,D\right)\right\} - \exp\left(-\frac{I_a}{I_{si}}\right)\right]$$

Equation 6

where:

e = 2.718

Ia = the average incident light intensity during daylight hours just below the surface, assumed to average 0.9 I/f, ly/day

Isi = the saturating light intensity of the ith phytoplankton group, ly/day

Ke = the light extinction coefficient, computed from the non-algal light attenuation, Ke', and the phytoplankton self-shading attenuation, Keshd, m^{-1}

I = incident solar radiation, ly/day

f = fraction of day that is daylight, unitless

D = depth of the water column or model segment, m

Ke = total light extinction coefficient, m^{-1}

where the total light extinction is computed from a base value to which the impacts of algal shading and non-algal light attenuation are added. The formulation may be used in two ways, at the user's option. The use may input diel variations in light (f=1) or daily average light (f=fraction of daylight). The algal self shading coefficient in FLWASP is computed from

$$KE_{SHD} = KE_{SHDMult} \ T_{CHLA}^{KE_{SHDExp}}$$

Equation 7

where

KE_{SHD} = self shading coefficient

$KE_{SHDMult}$ = self shading multiplier

KE_{SHDExp} = self shading exponent

T_{CHLA} = total chlorophyll$_a$ concentration (summed over the three groups)

and the light related constants are tabulated below.

Table 4. MPM light constants

Light Option (1 uses input light; 2 uses calculated diel light)
Multiplier for Self Shading (Mult * TCHLA^Exp)
Exponent for Self Shading (Mult * TCHLA^Exp)
Include Algal Self Shading Light Extinction in Steele (0=Yes, 1=No)
Background Light Extinction Coefficient (1/m)
Detritus & Solids Light Extinction Multiplier
DOC Light Extinction Multiplier

2.2.4 Nutrients

For the MPM model, it is assumed that the phytoplankton population in question follows Monod growth kinetics with respect to the important nutrients, where the rate multiplier for growth is computed from

$$X_N = \min\left(\frac{DIN}{K_{MN} + DIN}, \ \frac{DIP}{K_{MP} + DIP}, \frac{DISi}{K_{MSi} + DISi}\right)$$

Equation 8

where DIN is dissolved inorganic nitrogen, DIP dissolved inorganic phosphorus, DISi is dissolved inorganic silica, K_{MN} is a half-saturation concentration for nitrogen, K_{MP} the half-saturation concentration for phosphorus, and K_{MSi} the half-saturation concentration for silica (concentration at which the rate multiplier is 0.5).

In this formulation, DIN includes both ammonia and nitrate-nitrogen (the sum of the two concentrations). Since ammonia is typically taken up by algae preferentially to nitrate, a preference factor is computed to estimate the fraction of uptake from ammonia (P_{NH3}) and from nitrate ($1-P_{NH3}$).

$$P_{NH3} = C_{NH3}\left(\frac{C_{NO3}}{(K_{mN}+C_{NH3})(K_{mN}+C_{NO3})}\right) + C_{NH3}\left(\frac{K_{mN}}{(C_{NH3}+C_{NO3})(K_{mN}+C_{NO3})}\right)$$

Equation 9

For the case where there is N fixation, such as by some blue-green algae, it is assumed that the DIN nutrient multiplier =1. However, it is important to distinguish between N fixation and N utilization as it impacts uptake of nitrogen species. Therefore, for N fixation the multiplier is computed using the following formulations

$$X_{DIN,1} = \frac{DIN}{K_{MN}+DIN}$$

$$X_{DIN,2} = \frac{K_{MN}}{K_{MN}+DIN}$$

$$and\ X_{DIN,1} + X_{DIN,2} = 1$$

Equation 10

where $X_{DIN,1}$ is the fraction of growth whereby N is utilized (N is consumed) and $X_{DIN,2}$ is that growth fraction where N is fixed. The constants used for nutrient limitation are tabulated below.

Table 5. MPM nutrient growth related constants for Phytoplankton group i (i=1 to 3)

Phytoplankton Maximum Growth Rate Constant @20 °C for Group i (1/day)
Phytoplankton Growth Temperature Coefficient for Group i
Optimal Temperature for Growth for Group i (°C)
Shape parameter for below optimal temperatures for Group i
Shape parameter for above optimal temperatures for Group i
Optimal Temperature for Growth for Group i (°C)
Shape parameter for below optimal temperatures for Group i
Shape parameter for above optimal temperatures for Group i
Phytoplankton Half-Saturation Constant for P Uptake for Group i (mg P/L)
Phytoplankton Half-Saturation Constant for Si Uptake for Group i (mg N/L)
Nitrogen fixation option (0 no, 1=yes) for Group i

2.2.5 Phytoplankton Losses

Mechanisms included in MPM that contribute to the biomass reduction rate of phytoplankton include endogenous respiration, non-predatory mortality, grazing by herbivorous zooplankton, salt water toxicity and settling. The endogenous respiration rate of phytoplankton is the rate at which the phytoplankton oxidize their organic carbon to carbon dioxide per unit weight of phytoplankton organic carbon. Respiration is the reverse of the photosynthesis process and, as such, contributes to the reduction in the biomass of the phytoplankton population. If the respiration rate of the phytoplankton as a whole is greater than the growth rate, there is a net loss of phytoplankton carbon or biomass. The endogenous respiration rate is temperature dependent (Riley, 1949) and is determined via

$$K_{iR}(T)=K_{iR}\left(20^{\circ}C\right)\Theta_{iR}^{(T-20)}$$

Equation 11

where:

$K_{iR}(20EC)$ = the endogenous respiration rate at 20EC for algal species I, day^{-1}

$k_{iR}(T)$ = the temperature corrected rate, day^{-1}

Θ_i = temperature coefficient, dimensionless

A second loss mechanism included for each group is death. Death in MPM is represented as the sum of three processes: natural death or mortality, salinity toxicity, and grazing. The natural death term is represented by a first-order rate constant ($k_{i,D}$) which is not temperature corrected. The death of for example fresh water algae introduced to a saline environment is referred to here as salinity toxicity and the death rate is modeled using:

$$S_{TOX}(i)=S_{TF(i)}\frac{Sal}{Sal+K_{sal(i)}}$$

Equation 12

where

$S_{TF(i)}$ = salinity enhanced death rate for algal group i (day^{-1}),

Sal = salinity (ppt), and

$K_{sal(i)}$ = half-saturation constant for salinity mortality.

The loss rate due to grazing by zooplankton is modeled as in previous versions of WASP. However, since multiple algae groups are available, a grazing preference factor was included in

MPM. Note that the zooplankton population dynamics in this and previous versions of WASP are described by the user, not simulated.

A final loss rate is due to settling. Unlike previous versions of WASP, in MPM, a specific settling rate is specified for each algal group as a model parameter in units of m/day. The total loss rate (day-1) is then the sum of the individual loss rates:

$$D_i = k_{iR}(T) + k_{iD} + k_{iGZ}(t)Z(t) + S_{TOX}(i) + v_{s,i} / H$$

Equation 13

The constants associated with algal growth and removal processes are provided below. An additional series of constants is provided to indicate what fraction of the death is recycled to organic nutrients (as opposed to dissolved forms)

Table 6. Loss process constants for Phytoplankton group i (i=1 to 3)

Phytoplankton Respiration Rate Constant @20 °C for Group i (1/day)
Phytoplankton Respiration Temperature Coefficient for Group i
Phytoplankton Death Rate Constant (Non-Zoo Predation) for Group i (1/day)
Phytoplankton death rate due to salinity toxicity for Group i (1/day)
Salinity at which algal mortality is half maximum value for Group i (g/L)
Phytoplankton Zooplankton Grazing Rate Constant for Group i (1/day)
Grazability (0 to 1) for Group i
Optimal Temperature for Growth for Group i (°C)
Shape parameter for below optimal temperatures for Group i
Shape parameter for above optimal temperatures for Group i
Fraction of Phytoplankton Death Recycled to Organic Si for Group i

2.3 The Silica Balance

Previous versions of WASP did not include Silica state variables, which ere added to MPM since silica is an important nutrient for some algae, such as diatorms. Four silica variables are modeled in the modified model: phytoplankton silica (living particulate silica, as a stoichiometric fraction of the algal biomass), detrital silica (non-living particulate organic silica), available silica (dissolved and sorbed inorganic material), and particulate biogenic silica (non-living dissolved organic material). Available silica is divided into particulate and dissolved concentrations by spatially variable dissolved fractions, computed from predicted solids concentrations and a partition coefficient.

2.3.1 Planktonic Silica

Planktonic silica is not modeled as a separate state variable. Rather it is computed from the algal biomass (gC/m^3) and the user specified stoichiometric ratio for Si/C.

2.3.2 Detrital Silica

Detrital silica is a model state variable (Table 1). The sources and sinks of detrital silica state variable 15, Table 1) are

$$S_{15} = \left(\sum_{i=1}^{3} k_{iD} C_{p,i} a_{SiC} \, f_{Si,i} \right) - k_{SUA} C_{DSi}$$

Equation 14

where

S_{15} = source sink term for detrital silica (g/m^3-day)

$k_{i,D}$ = death rate of phytoplankton group i (day^{-1})

$C_{p,i}$ = concentration of phytoplankton group i (gC/m^3)

$a_{Si,C}$ = stoichiometric silica/Carbon ratio

$f_{Si,i}$ = fraction of Phytoplankton Death Recycled to Organic Si for Group i

k_{SUA} = dissolution rate of particulate organic (detrital) Si (day^{-1})

C_{DSi} = concentration of detrital Silica (gSi/m^3)

so that the processes represented include a source due to algal death and a sink due to dissolution of particulate organic Si.

2.3.3 Dissolved Organic Silica

Detrital silica is a model state variable (Table 1). The sources and sinks of detrital silica state variable 15, Table 1) are

$$S_7 = \left(\sum_{i=1}^{3} k_{iR}(T) C_{p,i} a_{SiC} \, f_{Si,i} \right) + k_{SUA} C_{DSi} - K_{m,DiSi} C_{DiSi}$$

Equation 15

where

S_7 = source sink term for dissolved organic silica (g/m^3-day)

$k_{i,R}(T)$ = respiration rate of phytoplankton group i, temperature corrected (day^{-1})

$C_{p,i}$ = concentration of phytoplankton group i (gC/m^3)

$a_{Si,C}$ = stoichiometric silica/Carbon ratio

$f_{Si,i}$ = fraction of Phytoplankton Death Recycled to Organic Si for Group i

k_{SUA} = dissolution rate of particulate organic (detrital) Si (day_{-1})

C_{DSi} = concentration of detrital Silica (gSi/m^3)

$k_{m,DiSi}$ = dissolution rate of dissolved organic Si (day^{-1})

C_{DiSi} = concentration of dissolved organic Silica (gSi/m^3)

so that the processes represented include sources due to algal respiration and dissolution of detrital silica and a loss to dissolution of dissolved organic Si.

2.3.4 Dissolved and Sorbed Inorganic Silica

Dissolved inorganic silica (SiO_2; state variable 6 in Table 1) represents the form, when dissolved, available for algal growth. The sources and sinks for dissolved and sorbed inorganic silica are

$$S_6 = \left(\sum_{i=1}^{3} \left[k_{iR}(T)(1 - f_{Si,i}) + k_{i,D}(1 - f_{Si,i}) - Gp,i \right] a_{SiC}\, C_{p,i} \right) + K_{m,DiSi} C_{DiSi} - \sum_{j=1}^{3} f_{D,ISi,j} \frac{Vs,j}{H} C_{ISi}$$

Equation 16

S_7

where

S_6 = source sink term for dissolved inorganic silica (g/m^3-day)

$k_{i,R}(T)$ = respiration rate of phytoplankton group i, temperature corrected (day^{-1})

$k_{i,D}$ = death rate of phytoplankton group i (day^{-1})

Gp,i = growth rate of phytoplankton group i (day^{-1})

$C_{p,i}$ = concentration of phytoplankton group i (gC/m^3)

$a_{Si,C}$ = stoichiometric silica/Carbon ratio

$f_{Si,i}$ = fraction of phytoplankton and respiration recycled to organic si for Group i

C_{ISi} = concentration of dissolved inorganic Silica (gSi/m^3)

$k_{m,DiSi}$ = dissolution rate of dissolved organic Si (day^{-1})

C_{DiSi} = concentration of dissolved organic Silica (gSi/m^3)

$f_{P,ISI,j}$ = fraction particulate of inorganic silica sorbed onto solid type j (three solids types and computed using partitioning relationships)

$V_{s,j}$ = settling velocity of solid type j (m/day)

H = depth of model segment (m)

and the processes included are sources due to algal respiration, algal death and dissolution of organic silica and sinks due to algal growth and settling of the sorbed fraction (onto one or more of the three solids types).

Model constants for Silica are tabulated below.

Table 7. MPM Silica Constants

Silica Partition Coefficient to Water Column Solids 1 (L/kg)
Silica Partition Coefficient to Water Column Solids 2 (L/kg)
Silica Partition Coefficient to Water Column Solids 3 (L/kg)
Dissolved Organic Silica Mineralization Rate Constant @20 °C (1/day)
Dissolved Organic Silica Mineralization Temperature Coefficient
Phytoplankton Half-Sat. for Mineralization Rate (mg Phyt C/L)

3 MPM Parameters and Time Functions

The parameters in the MPM model have been modified from previous versions of WASP and are tabulated below. These parameters are segment specific (may be varied by segment) and, for some parameters, may also be varied with time using the time functions also tabulated below. The environmental parameters and time functions allow specification of environmental properties (such as temperature) that effect the MPM computations but are not predicted by MPM. The reader is referred to the WASP user's manual (Wool et al. 2006) for a more detailed discussion of the role and relationships between model parameters and time functions.

Table 8. MPM model parameters

1	Water Velocity Function for Segment (1 - 4)
2	Temperature of Segment (Degrees C or Multiplier)
3	Temperature Time Function for Segment Temperature (1 - 4)
4	Light Extinction for Segment (per meter or multiplier)
5	Ice Cover Time Function to use for Segment (1 - 3)
6	Benthic Ammonia Flux (mg/m2-day)
7	Benthic Phosphate Flux (mg/m2-day)
8	Sediment Oxygen Demand (g/m2-day)
9	Incoming Solar Radiation Multiplier (dimensionless)
10	Measured Segment Reaeration Rate (per day)
11	Zooplankton Population

12	Fraction Light Intercept by Canopy
13	Fraction of Bottom of Segment Covered by Benthic Algae
14	Segment elevation above sea level (m)
15	Dam Elevation (meters)
16	Dam Pool WQ Coefficient
17	Dam Type Coefficient
18	Tsvigolo Escape Coefficient
19	BOD(1) Decay Rate Scale Factor
20	BOD(2) Decay Rate Scale Factor
21	BOD(3) Decay Rate Scale Factor
22	Segment Scale Factor for Wind
23	Wind Speed Time Function to use for Segment (1 or 2)
24	Settling Rate of Segment Solids Type 1 (m/day)
25	Settling Rate of Segment Solids Type 2 (m/day)
26	Settling Rate of Segment Solids Type 3 (m/day)
27	Settling Rate of Segment Phytoplankton Group 1 (m/day)
28	Settling Rate of Segment Phytoplankton Group 2 (m/day)
29	Settling Rate of Segment Phytoplankton Group 3 (m/day)

Table 9. MPM Model Time Functions

1	Water Temperature Function 1 (°C)
2	Water Temperature Function 2 (°C)
3	Water Temperature Function 3 (°C)
4	Water Temperature Function 4 (°C)
5	Solar Radiation (Langleys/day)
6	Fraction Daily Light (fraction)
7	Wind Speed Time Function 1 (m/sec)
8	Wind Speed Time Function 2 (m/sec)
9	Light Extinction Function (per meter)
10	Air Temperature (°C)
11	Velocity Function 1 (m/sec)
12	Velocity Function 2 (m/sec)

13	Velocity Function 3 (m/sec)
14	Ammonia Benthic Flux (mg/m2-day)
15	Phosphorus Benthic Flux (mg/m2-day)
16	Ice Cover Function 1 (fraction ice free)
17	Ice Cover Function 2 (fraction ice free)
18	Ice Cover Function 3 (fraction ice free)
19	Shading Function (fraction unshaded)
20	Zooplankton Population (count)
21	Reaeration Function (per day)
22	Settling rate for algal group 1 (m/day)
23	Settling rate for algal group 2 (m/day)
24	Settling rate for algal group 3 (m/day)

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