User's Guide to the water-quality part of the Bays Eutrophication Model (BEM)

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User's guide to the water-quality part of the Bays Eutrophication Model (BEM).

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1. INTRODUCTION

This manual is a user's guide specifically for the water-quality part of the Bays Eutrophication Model (BEM). In this report we will refer to the water-quality part of BEM as BEMwq, and the hydrodynamic part of BEM as ECOMsi.

Supported by the MWRA, BEM was developed to study the water quality and ecosystem dynamics, and predict the environmental conditions in Massachusetts Bay (MB) (Figure 1-1). BEMwq is based on the Row-Column AESOP (RCA) developed by HydroQual, Inc., and has been calibrated and improved over the last ten years (HydroQual and Normandeau 1995, HydroQual 2000, 2003, Jiang and Zhou 2004a, 2006).

BEMwq is based on RCA 2.0. A newer version, RCA.3.0, recently developed by HydroQual (HydroQual, 2004) included some modifications and re-structuring of the model. The major changes from RCA 2.0 to RCA 3.0 are (1) implementation of an integer "clock" to the control the numerical simulation, and model input and output, (2) greater checking for input errors, and (3) use of more comment or header records for inputs (page 6, HydroQual 2004). However, the general model structure and the majority of model implementation remain unchanged. BEMwq has also evolved over the last 10 years. A brief summary of the different versions is presented in Table 1-1. BEMwq is coupled to the Massachusetts Bay hydrodynamic model, which is based on the semi-implicit Estuarine Coastal Ocean Model (ECOMsi), a variant of the Princeton Ocean Model (POM) (Blumberg and Mellor 1987, Blumberg 1991, HydroQual and Signell 2001, Jiang and Zhou 2004b).

This manual will serve as a supplement to the general user guide for RCA 3.0 (HydroQual 2004) by providing more detailed instructions and descriptions of BEMwq. The focus will be on model parameters and implementation specifically for BEMwq. Therefore, the description of BEMwq will be heavily referenced to the user manual of RCA 3.0 (HydroQual 2004), which can be obtained by sending an online request to HydroQual, Inc at http://www.hydroqual.com/. Note that BEMwq is based on RCA2, but the manual for RCA3 is still applicable to BEMwq. In the following, the same notations as those in RCA 3.0 will be used, unless specifically noted. The descriptions will be based on the implementation used for the 2004 simulation of MB water quality (Jiang and Zhou, 2006) and sample files will be taken from there as well.

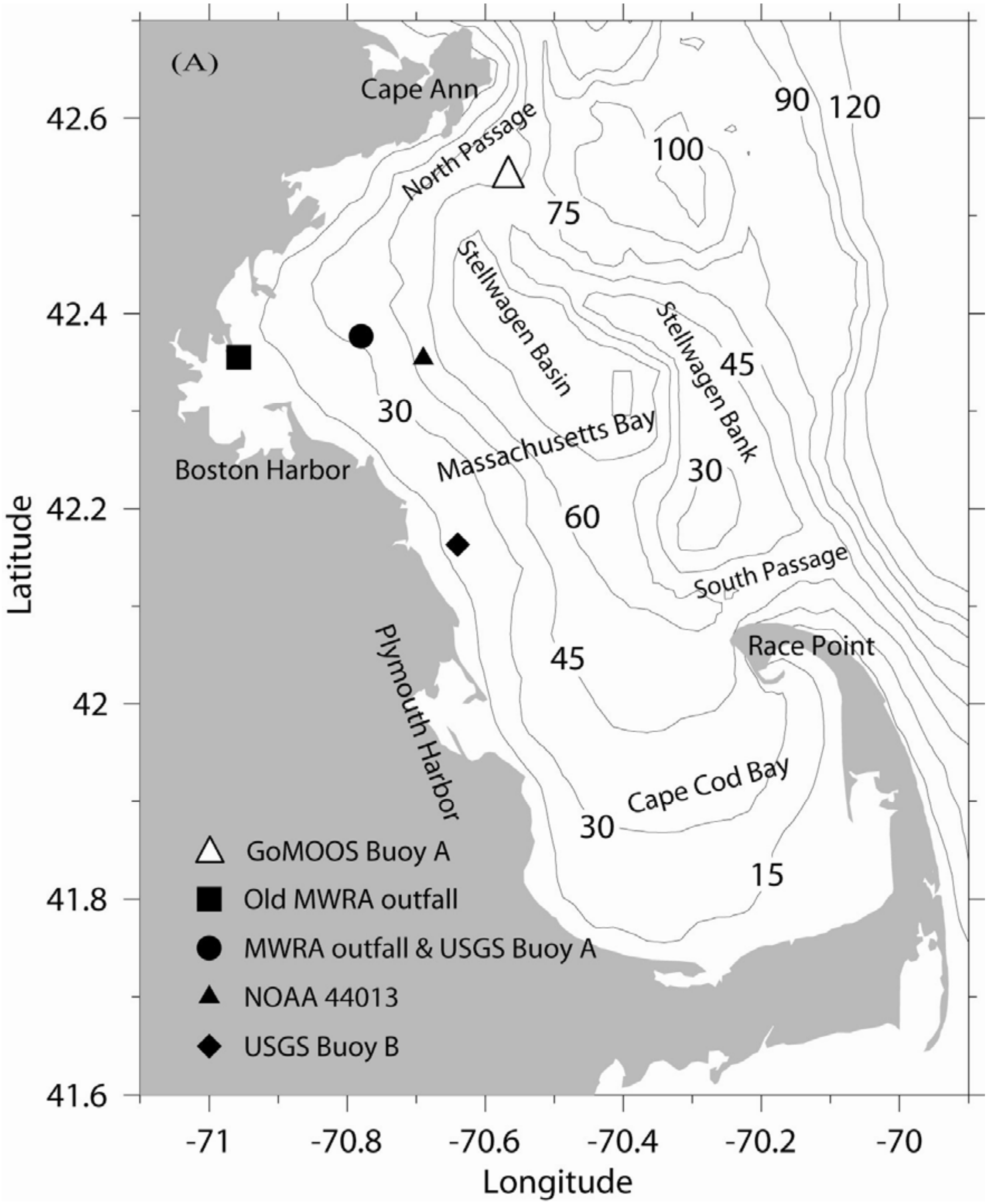

Figure 1.1. Physical setting and bathymetry of Massachusetts Bay.

Table 1-1. A brief history of BEMwq.

Simulation Period	Major features	Reference
1989–1992	Basic model setup. Coarse model grid, sigma-coordinate, two phytoplankton groups, manual OBCs construction.	HydroQual and Normandeau (1995)
1992–1994*	Improvements in OBCs with new monitoring stations and hydrodynamic model	HydroQual (2000)
1998–1999*	Fine model grid, 3 phytoplankton groups	HydroQual (2003)
2000–2001*	Objective OBCs construction	Jiang and Zhou (2004a)
2002–2004*	Improved air-sea O_2 formulation	Jiang and Zhou (2006)

*For later simulations, only improvements relative to the immediate previous simulations are listed.

2. MODEL DESCRIPTION

2.1 Model Domain and Grids

The model domain covers the entire MB system with the open boundary connecting Cape Ann and the outer edge of Cape Cod (Figure 2-1). This domain is smaller than that of the hydrodynamic model because of the limitation of available data. The model grids in the current version of BEMwq are essentially the same as the grids used for the hydrodynamic model (*e.g.*, Jiang and Zhou 2004b) except that the top three sigma layers in the hydrodynamic model are integrated to one sigma layer in BEMwq. BEMwq has 54×68 horizontal grids and 10 vertical layers.

2.2 Model Structure

BEMwq simulates the major biogeochemical processes without explicitly simulating zooplankton. A brief summary of the biogeochemical processes in the model is as follows (see Appendices A and B). The cycling of nitrogen includes (1) consumption of dissolved inorganic nitrogen, the sum of ammonium, nitrite and nitrate, by phytoplankton photosynthesis, (2) decomposition of organic matter and 3) reduction of nitrate by denitrification (Figure 2-2, Appendix A). The living cells of phytoplankton are transformed into non-living organic matter by respiration, mortality, and zooplankton grazing. The grazing rate is subject to temperature modulation with the rate set as a 10% daily removal of phytoplankton standing stocks at 20° C. The decomposition of organic matter by bacteria in the water column involves two steps: breakdown of particulate organic nitrogen (PON) to dissolved organic nitrogen (DON), and DON remineralization to ammonia. Vertical mixing at the water-sediment interface returns sediment-produced dissolved inorganic nitrogen to the water column. Denitrification releases nitrous gas directly to the atmospheric.

The biogeochemical cycling of carbon and phosphorus are similarly simulated with one dissolved inorganic form of phosphorus and several organic forms of phosphorus and carbon (dissolved inorganic carbon is not simulated), while the silicon cycling is simulated with two components only: dissolved silicon and biogenic silicon. Oxygen generally follows the carbon cycle with additional sources from the air-sea oxygen exchange. The model equations for C, P, and Si can be found in RCA 3.0 (HydroQual 2004).

2.3 Model Variables

The current version of BEMwq has 26 prognostic variables, which include salinity, three phytoplankton groups (winter/spring, summer and fall), four type of nutrients (C, N, P, Si) and related organic components (dissolved and particulate organic matters), and dissolved oxygen (DO) (Table 2-1). The model also includes a variable for trace metal (TAM), which is not activated at present.

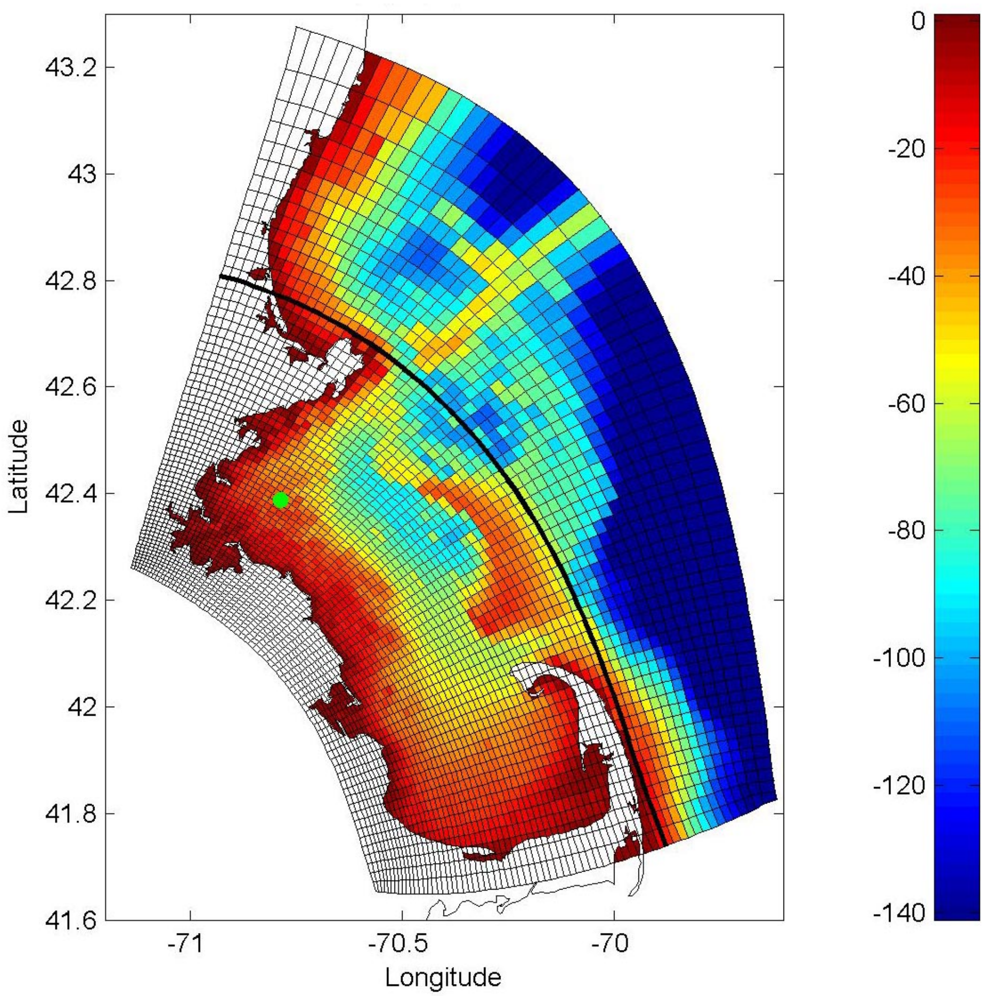

Figure 2-1. The BEM model domain grid. The larger domain is for hydrodynamic model and the domain for BEMwq is limited to the western portion of the thick solid line.

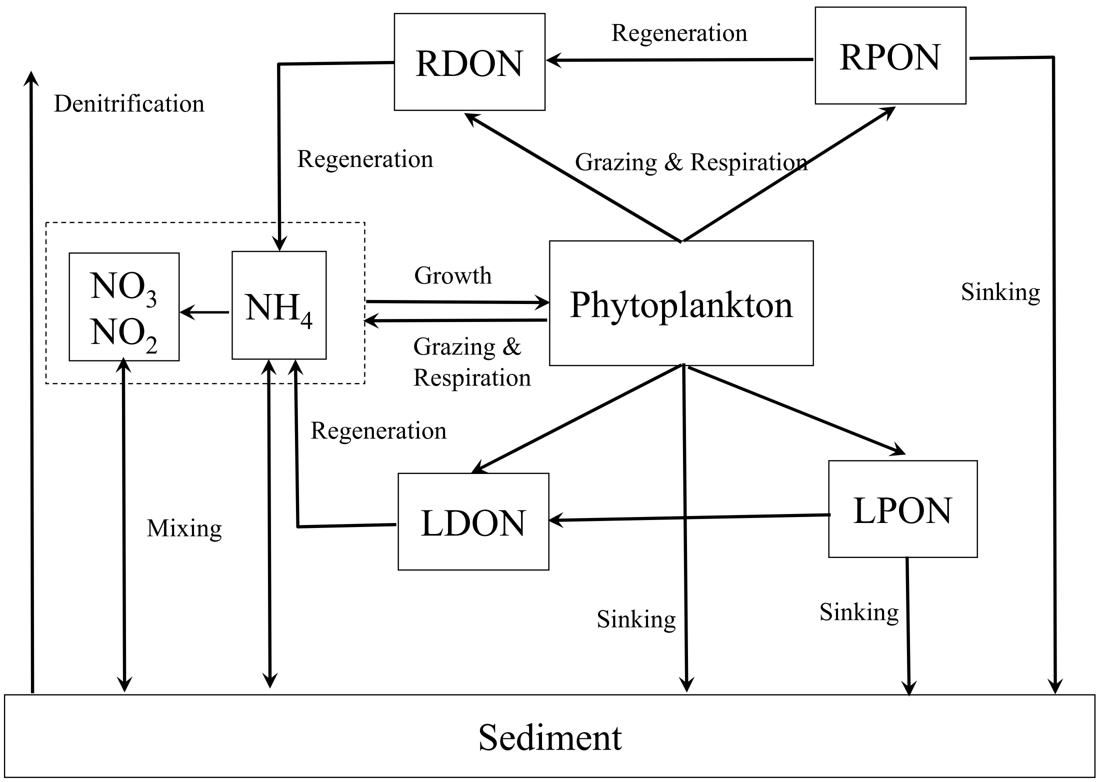

Figure 2-2. The BEMwq structure as represented by the nitrogen cycle.

Table 2-1. Model variables.

System No.	Description	Units
1	Salinity	ppt
2	Phytoplankton winter/spring group (diatoms)	mg C l^{-1}
3	Phytoplankton summer group	mg C l^{-1}
4	Particulate organic phosphorous – refractory component	mg P l^{-1}
5	Particulate organic phosphorous – labile component	mg P l^{-1}
6	Dissolved organic phosphorous – refractory component	mg P l-1
7	Dissolved organic phosphorous – labile component	mg P l^{-1}
8	Total dissolved inorganic phosphorous	mg P l^{-1}
9	Particulate organic nitrogen – refractory component	mg N l^{-1}
10	Particulate organic nitrogen – labile component	mg N l^{-1}
11	Dissolved organic nitrogen – refractory component	mg N l^{-1}
12	Dissolved organic nitrogen – labile component	mg N l^{-1}
13	Total ammonia (ammonia in water and phytoplankton cells)	mg N l^{-1}
14	Nitrite + nitrate	mg N l^{-1}

System No.	Description	Units
15	Biogenic silica	mg Si l^{-1}
16	Total silica – (silica in water and phytoplankton cells)	mg Si l^{-1}
17	Particulate organic carbon – refractory component	mg C l^{-1}
18	Particulate organic carbon – labile component	mg C l^{-1}
19	Dissolved organic carbon – refractory component	mg C l^{-1}
20	Dissolved organic carbon – labile component	mg C l^{-1}
21	Dissolved organic carbon – reactive component	mg C l^{-1}
22	Dissolved organic carbon – algal exudate	mg C l^{-1}
23	O2* - aqueous oxygen	mg O_2 l^{-1}
24	Dissolved oxygen	mg O_2 l^{-1}
25	Total active metal (TAM)	mmol l^{-1}
26	Phytoplankton fall group	mg C l^{-1}

2.4 Forcing

The model is forced by nutrient inputs from land-based sources (including rivers, sewage effluent, and combined sewage overflow), atmospheric loads, and open boundary. The system is also forced by the biota input at the open boundary and by air-sea oxygen exchange. The physical forcing includes surface forcing (solar radiation and winds) and hydrodynamic processes. Day length is also required to correctly simulate the diurnal cycle of solar radiation. The hydrodynamic variables such as temperature, currents, and turbulent mixing are derived from the hydrodynamic model, using a collapse program developed by HydroQual, Inc. Table 2-2 lists all the sources of these forcing data, the frequency of observations, and the frequencies used in the model. For a general description of these forcing conditions, see previous reports (*e.g.*, HydroQual 2003, Jiang and Zhou 2004a, 2006).

Table 2-2. Sources of forcing data for BEMwq.

Parameters	Frequencies in the model	Frequencies of original data	Filtering	Sources
Winds	daily	hourly	no	NDBC 44013
Solar radiation	daily	hourly	no	WHOI
Boundary conditions	bi-weekly	monthly	objective interpolation	MWRA, SBNMS
River loadings	weekly	daily flow and monthly nutrients	no	USGS
Effluent	weekly	Weekly	no	MWRA
Non-MWRA effluent, CSO, Ground waters	monthly	various	“climatological” mean	Menzie-Cura, MWRA
Hydrodynamic variables	hourly	minutes	collapse	ECOMsi

2.5 Model Equations

The model equations governing the nitrogen cycle in the water column are shown in Appendix A. A complete set of model equations for the biogeochemical processes can be found in HydroQual (2004).

The air-sea oxygen exchange (F_{O2}) is calculated through solubility process,

$$F_{O2}=k*(DO_{sat}-DO), \tag{2.1}$$

where DO is the water oxygen concentration, DO_{sat} is the saturation concentration of oxygen at the sea surface as calculated by Hyer *et al.* (1971), and k (unit: m/day) is the piston velocity for air-sea O_2 exchange. The piston velocity largely depends on wind speed (w, m/sec) and water temperature. In the current BEMwq, an empirical formula by Wanninkhof (1992) is used. At 20°C water temperature, the formula can be written as

$$k = 0.1w^2 \tag{2.2}$$

This formulation was used in the 2002–2004 simulations (Jiang and Zhou 2006). In earlier simulations, the formulation by Banks and Herrera (1977) was used to calculate the piston velocity. For a comparison of these two formulae, see Jiang and Zhou (2006).

2.6 Numerical Schemes

There are several options to the numerical solution of the advection-diffusion-reaction equations in BEMwq, which are detailed in HydroQual (2004). The standard solution is an explicit upwind scheme with the Smolarkiewicz correction (Smolarkiewicz 1984).

2.7 Open Boundary Conditions

The open boundary conditions are specified using the values derived *in-situ* observations. In simulations 2000-01 and 2002-04, these values were derived from an objective interpolation procedure (Jiang and Zhou 2004a, 2006), while earlier simulations used manually derived values (HydroQual 2000, 2003).

2.8 Initial Conditions

The initial conditions for each year were derived from modeled results at the end of the previous year and no spin-up was used in the simulation.

2.9 Sediment Submodel

The sediment component follows the framework developed by Di Toro (2001). The 3-G model proposed by Westrich and Berner (1984) is adopted to simulate the sediment diagenesis processes. The sediment is simulated with two layers: an aerobic layer and an anaerobic layer. For a complete description of sediment component and model equations, see Appendix A in HydroQual (2004).

2.10 Interface with the Hydrodynamic Model

The BEMwq is offline-coupled with the hydrodynamic model (HydroQual, 2000). The modeled hydrodynamic variables such as temperature, salinity, currents, and turbulent mixing coefficients from the hydrodynamic model are averaged in every hour and stored to be used as physical forcing to the water quality model. A collapse program (colla3d.f, which comes with the ECOMsi, not in the water quality model package) is used to average hydrodynamic variables in the top three layers of the ECOMsi and assign the resulted values to the top sigma layer in BEMwq.

2.11 Interface between Water Column and Sediment Submodels

The interactions between the water column and the sediment are simulated through the sedimentation of particulate organic matter and the mixing of nutrients (Figure 2-2). The sedimentation rates of organic carbon, nitrogen, phosphorus, and silica, and the bottom layer of nutrient concentrations are fed to the sediment submodel. The sediment submodel calculates the sediment nutrient concentrations and then mixing fluxes of nutrients between the water-sediment interface, which are then added back to (subtracted from if negative) the bottom layer of the water column.

2.12 Model Parameters

Model parameters for BEMwq were chosen based on literature and empirical values. After calibration during the early phase of model development, a set of parameter values were chosen and kept the same for the simulations of 1998–1999 (HydroQual, 2003) and 2000–2004 (Jiang and Zhou, 2004a, 2006). There are three types of parameters: (1) constants, (2) two-dimensional (2-D) parameters, and (3) three-dimensional (3-D) model parameters. There are 138 model constants in the current BEMwq. Those parameters associated with the nitrogen cycle are listed in Appendix B.

Some model parameters are allowed to vary horizontally and hence are two-2-D parameters. These parameters include the piston velocity of air-sea oxygen exchange (KL), base light attenuation coefficient (kbase, see Eq. A10), and settling efficiencies for three phytoplankton groups. In BEMwq, KL is recalculated using either Wanninkhof (1992) formulation (2002–2004 simulations) or that by Banks and Herrera (1977) (earlier simulations) as noted above. The settling efficiencies are non-dimensional parameters (ranges 0–1), which determine the depositional fraction of the sinking fluxes of particulate organic matter at the bottom layer. No 3-D parameters are used presently.

2.13 Fortran Programs

The model is implemented through a number of programs written in Fortran 77 programming language. A list of these programs and a brief description of each are shown in Table 2-3.

Table 2-3. Model programs.

File Name	Description
Makefile	make file for compiling
RCACM	definitions of arrays and common blocks for the water column
SEDCM	definitions of arrays and common blocks for the sediment submodel
fmter.f	error messages print out
massbay26.f	water column ecosystem model, and time-history dumps (RCAF11)
rca.f	main program
rca01.f	initialization
rca02.f	input print control parameters and integration history from standard input
rca03.f	input model geometry and initial transport fields
rca04.f	input boundary conditions
rca05.f	input nutrient loading from point sources, non-point sources, fall-line loads, and atmospheric loads
rca06.f	input model parameters (including 2-d parameters), constants and time-variable forcing (light, day length, solar radiation)
rca07.f	input initial conditions
rca08.f	synchronize forcing if simulation starts other than time equal to zero

File Name	Description
rca09.f	an output routine for immediate dumps
rca10.f	update of nutrient loading
rca11.f	update of boundary conditions
rca12.f	print out user requested dumps
rca13.f	update the time-variable forcing (light, day length, solar radiation)
rcabyss.f	generate a system dump file from master dump RCAF11 to standard output
rcadwrit.f	detailed dump for selected segments (RCAF13)
rcaexp.f	master subroutine to integrate the advection-diffusion equation (time: explicit, 1st order Euler. Space: upwind)
rcaexp1.f	setup of advection term (called by rcaexp)
rcaexps.f	master subroutine to integrate the advection-diffusion equation (time: explicit, 1st order Euler. Space: upwind with Smolarkiewicz correction)
rcaimp.f	master subroutine to integrate the advection-diffusion equation (time: implicit, Gauss-Seidel iteration. Space: upwind)
rcaimp1.f	setup of advection term (called by rcaimp)
rcamess.f	messages for concentrations adjustment during simulation
rcamprof.f	concentrations averages over the domain for sigma-coordinate corrections
rcaprnt.f	general printout
rcass.f	master subroutine for solution of steady-state equations
sedmodlsubs.f	collection of sediment subroutines
sinter.f	linter interpolation subroutine
stoich.f	definitions of nutrient to carbon ratios
vssedmodl.f	sediment submodel (parameters, initial conditions, call for other sub-routines and outputs (RCAF14)

3. MODEL INPUTS

The BEMwq requires a number of input files to specify model geometry, forcing conditions, and model parameters (Table 3-1). The model also requires a file to pre-define the run controls, which include the simulation options, model input and output files, and choices of output segments (segment is defined as a model grid point or grid points defined by (i, j, k).

In general, the files for forcing conditions in BEMwq include: (1) header line, (2) first record, and (3) subsequent records. The header line defines the input options, i.e. whether the forcing is constant or time-variable, and – for boundary conditions – options controlling the spatial distribution of the forcing along the boundary. The first record defines the time “NXPST” (calendar day) of the record (usually zero, i.e. midnight on January 1), the number of segments, scale factor, segments, and values corresponding to these segments. A segment is referred to a model grid point defined by the indices of model grid (column, row, and layer). The number of segments, segment locations and scale factors may vary between model systems (model variables). The total number of model systems (NOSYS) in the current BEMwq is 26. The actual values used in the model are derived by multiplying the specified values with the scale factor. (The scale factor is simply used to scale the variables so that after scaling, variables would have similar range, because some variables have large values while others have smaller values.) If the number of segments for a model variable is zero then there is no forcing for this variable and no segment locations or values are given. The subsequent records will consist only of the time and values at those pre-defined segments in the first record. For those model variables with a zero segment, there will be no values in subsequent records. The truncated files used for the 2004 simulation are presented in Tables 3-2–3-6. The organizing structures for these files in BEMwq are different from those in the RCA3.0 (HydroQual 2004), though input options for each file remain the same.

Once finishing reading the first record, the model will read the time for the next record, which will be stored for checking. Once the model time clock exceeds NXPST, the model will update loading by reading the second record (using program rca10.f), which only contains values for valid systems at the specified segments. Similar procedures apply to all other subsequent records. A summary of the control options for nutrient inputs is shown in Table 3-7.

The input structure of the files for model parameters (water column and sediment) and run controls are quite complicated (Tables 3-8–3-10). These files have very similar structures to those used in the RCA 3.0 (HydroQual 2004) and many elements in these files have been explained in details in the RCA 3.0 user manual (HydroQual 2004). Therefore, we will briefly summarize these explanations here. The correspondences between the elements in Tables 3-8–3-10 and the RCA 3.0 manual are shown in Table 3-11, which lists the line numbers in each table and their corresponding page and section numbers in RCA 3.0 user manual. Elements that have no matches in RCA 3.0 will be described here.

In the following, ISYS is used as an integer indicating the index of model system (ranges 1-NOSYS), and the following syntax is used:

A(I), I=1, N ---- a Fortran do loop for an array with index I (ranges 1-N)

Table 3-1. Model input files.

File Name	Actual Name	Type	Descriptions
STDIN	mbfull.inp2004	ASCII	Model run controls and some parameters
gcm_geom	gcm_geom	binary	Model geometry
wet_grid	wet_grid	binary	row, column (i, j) locations of the water segments
HDFILNA	gcm_tranWQf2004.1	binary	Transport supplied from ECOMsi
BCFLINA	bcf.2004.2wk	ASCII/bin	Boundary concentrations
PSFILNA	ps.2004.wk	ASCII/bin	Point-source loads
NPSFILNA	nps.2004	ASCII/bin	Non-point source loads
FLFILNA	model.fl2004	ASCII/bin	Fall-line loads
ATMFILNA	atmos2004.load	ASCII/bin	Atmospheric loads
ICFLINA	bin2004.ic	ASCII/bin	Initial conditions
PCFILNA	model.pcv.2004	ASCII	Model parameters, and time-functions
SEDFILNA	sed.inp	ASCII	Initial conditions, run controls, and model parameters for sediment sub-model

3.1 Point Sources

The point sources in BEMwq are sewage effluent in this area. The largest effluent was from the MWRA outfall, which was at Deer Island before September 6, 2000 and relocated to 15 km offshore in MB since then (Figure 1-1). The effluent at Deer Island is evenly distributed on 10 vertical layers, whereas the effluent at the new outfall is distributed on the bottom three vertical layers.

Table 3-2 shows a truncated input deck for point sources in the 2004 simulation. This file is first read by program rca05.f (Table 2-1). The header line (line 1) specifies the input option IPSOPT, which has two options,

IPSOPT	= 1	all point source loads are constant in time
	2	time-variable point source loads will be used

If IPSOPT=1, no time will be read, instead there will be only one record for model inputs, whereas if IPSOPT=2, the model will continue to read line 2 as input time (zero here).

Line 3 specifies the number of segment NOPS (ISYS) (ISYS is the index for model system) for the first model variable (ISYS=1), which is salinity (see Table 2-1). The NOPS have two options,

NOPS =	0	invalid system, no input
>	0	valid system, input followed

Because NOPS(1) is zero, no segments and values are followed for this model system. Similarly, line 4 and line 5 indicate no inputs for model system 2 and 3 (winter/spring and summer phytoplankton groups). Line 6 indicates there are 23 segments for system 4 (ISYS=4), which is refractory particulate organic phosphorus. Therefore the model continues to read the scale factor SCALPS (ISYS) (line 7), the segments IPS (row, column, layer) (lines 8–11), and the corresponding values BPS (lines 12–15).

The model will continue to read input information for all other model variables (lines 16–48), and then the time for next record (NXPST) in line 49. The subsequent records will be read when model time exceeds NXPST (rca10.f).

3.2 Non-point Sources

The non-point sources in BEMwq include CSOs and ground water discharges. A truncated input deck for the 2004 simulation is shown in Table 3-3. This input deck has essentially same structure as that for the point sources. The corresponding control parameters are: INPSOPT, NONPS, SCALNPS, INPS, BNPS, and NXNPST (Table 3-7). The non-point sources update monthly, which is less frequent than the bi-weekly update for point sources.

3.3 Fall-line Loads

The fall-line load in BEMwq includes Charles River, Neponset River, Mystic River and other small tributaries. A truncated input deck of the fall-line sources for the 2004 simulation is shown in Table 3-3. This input deck has essentially same structure as that for the point sources. The corresponding control parameters are: IFLOPT, NOFL, SCALFL, IFL, BFL, and NXFLT (Table 3-7). The fall line flow updates every month.

3.4 Atmospheric Loading

The input deck of atmospheric loading has a different structure compared with those of the point and non-point sources. Because there is insufficient spatial information to determine the spatial distribution of the loadings, atmospheric loading is distributed uniformly over the model domain and no segment information is needed. A truncated input for the 2004 simulation is shown in Table 3-5, which is organized as follows,

- Header line
- Time of first record

- Option for the first system (NOATM)
- Scale factor
- Value
- …
- Time of second record
- Value
- …

The option NOATM defines if the system has valid input,
NOATM --------- 0 --- no valid input, no follow-up lines for this system
1 --- valid input, next two lines give the scale factor and value.

Table 3-5 indicates that only systems 7 (labile DOP), 8 (total DIP), 12 (labile DON), 13 (total NH4), 14 (nitrate), and 20 (labile DOC) have valid inputs from the atmosphere. The control parameters for atmospheric loads in the current BEMwq are IATMOPT, NXATMT, NOATM, SCALATM, and BATM. Atmospheric loads update monthly.

3.5 Open Boundary Conditions

The input structure of the open boundary conditions is similar to those of point sources and non-point sources with slight difference. A truncated input deck for the 2004 simulation is given in Table 3-6. The header line inputs two parameters: IBCOPT and IBCPLOPT. IBCOPT has four options,

IBCOPT =	1	Constant input, sigma level
	2	Time-variable input, sigma level
	3	Constant input, standard level
	4	Time-variable input, standard level

IBCPLOPT has two options,

IBCPLOPT =	0	Step function input
	1	Linear interpolation input

For a step function input, values at each record will be used until the next record is read. For a linear interpolation input, a second record will be read. The values between the two records will be linearly interpolated into the model time as final boundary conditions.
For sigma level option, the subsequent input structure is the same as those of point sources and non-point sources,

- Time
- Segment number
- Scale factor
- Segments
- Values

For a standard level option, there are two additional lines following the scale factor, which define the number of vertical layer and the water depths of the vertical layers. The depths of vertical layers are needed to allow the model interpolate the input file into model sigma level. The subsequent input has the following structure,

- Time
- Segment number (only count horizontal total segments)
- Scale factor
- Total standard level
- Depth of standard level
- Segments
- Values

The values at each segment will be interpolated to sigma level to give the final input values. The control parameters for open boundary inputs are listed in Table 3-7. In the current BEMwq, boundary conditions update bi-weekly.

3.6 Model parameters for the water column

As noted in section 2.12, there are several types of parameters: 2-D parameters, 3-D parameters, constants, and time-variable functions. A truncated input deck of model parameters for the 2004 simulation is shown in Table 3-8.

3.7 2-D parameters

In Table 3-8, line 1 specifies the total number of 2-D parameters and line 2 specifies the scale factor for each parameters. Six 2-D parameters are needed in the current BEMwq. Lines 14-68 specify the values of these parameters successively over the entire model domain, which means 54-68 numbers for each parameter. As noted in section 2.12, the values of KL will be replaced with values calculated from an empirical formulation in the current version of BEMwq. There are four settling efficiencies parameters for three phytoplankton groups and particulate organic matter, respectively, all of which are set to 1 in this model. The last 2-D parameter is kebase, which is the light attenuation coefficient for pure water (no phytoplankton is present) (see eq. A10).

3.8 3-D parameters

Line 69 specifies the number of 3-D parameters. Currently, no 3-D parameters are present and hence no follow-up lines for 3-D parameters.

3.9 Constants

Line 70 specifies the total number of constants used in BEMwq (water column only). In the current BEMwq, 138 constants are needed. Line 71-97 specifies these parameters. A descriptions of parameters related to nitrogen cycle is given in Appendix B. Descriptions for other parameters can be found in RCA3.0 manual, though parameter values may be different (HydroQual, 2004).

3.10 Time-variable function

Line 98 specifies the total number of time-variable functions and the interpolation option (ITVFPLOPT), which has two options,

ITVFPLOPT =	0	step function
>	0	linear interpolation between two values

For the step function option, the model will use one value throughout the time interval before it is updated. For a linear interpolation option, the model will read a second value and then linearly interpolate them into the model time.

In the current BEMwq, three time-variable functions are needed: solar radiation (unit: Langleys), fraction of daylight (ca. day length) and wind speed. Lines 99-143 specify the total records of each function and their values.

3.11 Initial conditions for the water column

The initial conditions for each year in BEMwq can be derived manually (cold start) or from the modeled results in the end of the previous year's simulation (hot start). In the simulations of 2002-2004, hot start is used. No spin-up is used in the simulation.

3.12 Run controls

A separate file is needed to specify options for controlling the simulation such as model input and output, integration options, etc. The input file for the 2004 simulation is shown in Table 3-9. The input format for run controls in BEMwq is very similar to that in RCA3.0 and many options are exactly the same as those in RCA3.0. No comment lines, however, are used in BEMwq input control file. In addition, the unit of time in BEMwq is day, while RCA3.0 uses seconds. Table 3-11 lists all of the control options that can be found in RCA3.0 user manual (HydroQual, 2004). We will only give brief description of these options below. Options that only apply to BEMwq will be explained in more details below.

Line 1 specifies the model descriptors, which include general options for model run, execution and listing, model title, state variables, and system bypass options. In BEMwq, there are 10 general options (line 1 in Table 3-9), which are listed in Table 3-11.

CYCLE specifies how the model initial conditions are read,
CYCLE ------ 0 ---- Cold start
1 ---- Hot start
LIST specifies if the model will export the nutrient inputs options above to standard output,
LIST --------- 0 --- No
1 --- Yes
IDIADGT determines if a real model run is needed,
IDIADGT ---- 0 ---- Yes, real simulation
1 ---- No, model will only check the input decks

The remaining three parameters (MODEL, ISER, and IRUN) are used to generate a text message describing the model run (not present in RCA3.0). In our example, it produces a message "MODEL 1 SERIES 0 RUN 1".

Lines 2–7 in Table 3-8 specify the model title, model variable and simulation description.

Line 8 determines the bypass options for each model system (0 —Yes, 1---No). In our case, system 25 (trace metal) will not be simulated.

Line 9 defines the model output options,
PRNTG ----------- time interval (unit: day) of global dumps
PRNTD ----------- time interval (unit: day) of detailed dumps
NDMPS ---------- number of segments for detailed dumps

If NDMPS > 0, then the model will read segment information from the next several lines (lines 10-31). And line 32 specifies the bypass options of detailed dump for each model system (0—dump, 1—no dump). In this example, model results for all model systems are dumped.

Line 33 specifies six special segments (each with three grid indices) for intermediate dump to the standard output, which is printed at time interval PRNTG.

Line 34 defines the model integration options:

INTGRTYP ------- 1 (upwind scheme) or 4 (upwind with Smolarkiewicz correction)
NEGSLN --------- 0 (negative solution not permitted) or 1 (allows negative solution)
SLCOPT --------- 0 (no sigma level correction) or 1 (with sigma level correction)

Line 35 defines time warp factors (integration step size, start time, and integration interval) (see HydroQual, 2004).

The model allows multiple time-steps in cases a small time step is needed for specific integration period. Line 36 specifies number of time steps (NSTEP). The following line (line 37) specifies the time-steps and the times before switching to another time step,

STEP(I), I=1, NSTEP ------- time step (day)
TBRK(I), I=1, NSTEP ------- time (day) until which ISTEP(I) is used.

In our case, NSTEP=1 and we use a same time step throughout the simulation period.

Line 38 specifies hydrodynamic file input options,

NOHYD ------------------ total number of time break for hydrodynamic inputs

ICOLLOPT ------------------ 0 – no grid collapse was performed
1 -- hydrodynamic input files were collapsed.
HYDCYCOPT ----------------- 0 – no reuse the transport if file end encountered
>0 – allows reuse of transport file.

LNDWTROPT ----------------- 0 – transport files include all grids
1 – transport files include only wet grids

The hydrodynamic conditions should be updated frequently (usually every several minutes).

Each update is called one time break. NOHYD defines the total time breaks. Option HYDCYCOPT defines whether the model allows the transport file to be re-used if the model encounters the end of the transport file (in our case, this is "Yes" or HYDCYCOPT=2). The next line (line 39) defines the first three time breaks (unit: day) for hydrodynamic input (HYBRK(I), I=1,3). With these, the other time is calculated as follows,

HYBRK (I) = HYBRK(2) + (HYBRK(3)-HYBRK(2))*I, I = 3, 4, …, NOHYD

Line 40 reads SCALRQ, SCALRX, SCALRY, SCALRZ, which define the scale factors to multiply advection and dispersion coefficients for x-direction (RCALRX), y-direction (SCALRY), and z-direction (SCALRZ). SCALQ is used to multiply the advection term, which is not required in RCA 3.0.

Lines 41–48 input the paths and file names for physical inputs, nutrient inputs and initial conditions (water column) along with the file format options (0 = binary, 1 = ASCII (1) format).

Lines 49–52 define the stability criteria (CMAX) for each model system. If one of the model variables exceeds its criterion, the model is assumed to be unstable and the program will be terminated.

Lines 53–56 define the minimum concentrations (CMIN) for each model system. If a model concentration of a variable is below its CMIN value, and the model current steps predict a negative value, then the "quartering" will not be executed even if NEGSLN=0.

Line 57 defines the dump option for global dump and detailed dump (IGDOPT, IDDOPT):

IGDOPT ------ 0—time-average over the specified interval PRNTG

1---snap shot

IDDOPT ------ 0--- time-average over the specified interval PRNTD
1—snap shot

Lines 58–69 specify sediment input file and other hydrodynamic model transport files. In the current BEM, hydrodynamic model results are stored in 12 files for each month.

Line 70 is blank and lines 71–72 specify the dump options (IVAR, 8 selected segments to output results at the end of the model simulation, and LYR). In the current case, no segments are specified.

3.13 Inputs for the sediment submodel

Inputs for the sediment submodel include initial conditions and model parameters. No run controls are needed for the sediment submodel. A truncated input deck is given in Table 3-10.

3.13.1 Initial conditions

Similar to the initial conditions for the water column, the initial condition for the sediment component can be derived manually (cold start) or from the model results of the previous year (hot start). In the 2002–2004 simulations, hot start was used. An example of the initial conditions for the 2004 simulation is shown in Table 3-10, lines 12–22.

3.13.2 Model parameters

All model parameters used in the sediment submodel are listed in Table 3-11 and the values used in the 2004 simulation are shown in Table 3-10. These parameters are all described in the RCA 3.0 user manual (HydroQual 2004) and the reference indices are listed in Table 3-11.

3.14 Other Model Required Files

Other required files are the grid information for model geometry (gcm_geom) and grid locations for wet (water) segments (wet_grid).

Table 3-2. Example of point source inputs.

2						**IPSOPT**															**1**
			0.00			**NXPST**															**2**
0						**NOPS**		**ISYS=1**													**3**
0						**NOPS**		**ISYS=2**													**4**
0						**NOPS**		**ISYS=3**													**5**
23						**NOPS**		**ISYS=4**													**6**
0.4536						**SCALPS**															**7**
40	56	10	46	51	10	43	54	10	19	50	10	27	57	10	33	56	10	5	21	10	**8**
17	33	10	17	33	10	19	59	1	19	55	1	19	55	2	19	55	3	19	55	4	**9**
19	55	5	19	55	6	19	55	7	19	55	8	19	55	9	19	55	10	31	48	8	**10**
31	48	9	31	48	10																**11**
63.2	4.2	0.4	3.1	85.2	4.2	3.6															**12**
6.3	1.4	0	0	0	0	0															**13**
0	0	0	0	0	0	305.9															**14**
305.94	305.9																				**15**
23																					**16**
0.4536																					**17**
40	56	10	46	51	10	43	54	10	19	50	10	27	57	10	33	56	10	5	21	10	**18**
17	33	10	17	33	10	19	59	1	19	55	1	19	55	2	19	55	3	19	55	4	**19**
19	55	5	19	55	6	19	55	7	19	55	8	19	55	9	19	55	10	31	48	8	**20**
31	48	9	31	48	10																**21**
115.9	7.6	0.8	5.7	156.3	7.7	6.7															**22**
11.5	2.6	0	0	0	0	0															**23**
0	0	0	0	0	0	560.9															**24**
560.89	560.9																				**25**
23																					**26**
0.4536																					**27**
40	56	10	46	51	10	43	54	10	19	50	10	27	57	10	33	56	10	5	21	10	**28**
17	33	10	17	33	10	19	59	1	19	55	1	19	55	2	19	55	3	19	55	4	**29**
19	55	5	19	55	6	19	55	7	19	55	8	19	55	9	19	55	10	31	48	8	**30**
31	48	9	31	48	10																**31**
10.6	0.7	0.1	0.5	14.2	0.7	0.6															**32**
1	0.2	0	0	0	0	0															**33**
0	0	0	0	0	0	50.99															**34**
50.99	50.99																				**35**
23																					**36**
0.4536																					**37**
40	56	10	46	51	10	43	54	10	19	50	10	27	57	10	33	56	10	5	21	10	**38**
17	33	10	17	33	10	19	59	1	19	55	1	19	55	2	19	55	3	19	55	4	**39**
19	55	5	19	55	6	19	55	7	19	55	8	19	55	9	19	55	10	31	48	8	**40**
31	48	9	31	48	10																**41**
21	1.4	0.1	1	28.4	1.4	1.2															**42**
2.1	0.5	0	0	0	0	0															**43**
0	0	0	0	0	0	102															**44**
101.98	102																				**45**
	.																				**46**
	.																				**47**
	.																				**48**
			14.00																		**49**
63.2	4.2	0.4	3.1	85.2	4.2	3.6															**50**
6.3	1.4	0	0	0	0	0															**51**
0	0	0	0	0	0	182.3															**52**
182.27	182.3																				**53**
115.9	7.6	0.8	5.7	156.3	7.7	6.7															**54**
11.5	2.6	0	0	0	0	0															**55**
0	0	0	0	0	0	334.2															**56**
334.15	334.2																				**57**
10.6	0.7	0.1	0.5	14.2	0.7	0.6															**58**
1	0.2	0	0	0	0	0															**59**
0	0	0	0	0	0	30.38															**60**
30.38	30.38																				**61**
	.																				**62**
	.																				**63**
	.																				**64**

Comments and line numbers are in bold fonts (which are not present in the real file).

Table 3-3. Example of non-point sources inputs.

2					**IPSOPT**																**1**
			0.00		**NXNPST**																**2**
0					**NONPS**		**ISYS=1**														**3**
0					**NOPS**		**ISYS=2**														**4**
0					**NONPS**		**ISYS=3**														**5**
188					**NONPS**		**ISYS=4**														**6**
0.4536					**SCALNPS**																**7**
24	59	1	23	58	1	22	57	1	21	58	1	20	58	1	19	59	1	18	59	1	**8**
18	60	1	18	61	1	18	62	1	18	63	1	19	63	1	17	59	1	16	59	1	**9**
15	60	1	14	61	1	14	60	1	13	59	1	12	60	1	12	59	1	12	58	1	**10**
13	58	1	12	56	1	11	56	1	10	56	1	10	55	1	10	54	1	10	53	1	**11**
11	52	1	12	52	1	13	51	1	12	50	1	11	50	1	10	50	1	13	49	1	**12**
14	49	1	15	48	1	16	47	1	15	47	1	16	46	1	19	45	1	19	44	1	**13**
19	43	1	19	42	1	19	41	1	19	40	1	19	40	1	19	40	1	10	9	1	**14**
11	8	1	13	7	1	15	6	1	16	6	1	17	6	1	18	5	1	19	5	1	**15**
20	5	1	21	5	1	22	5	1	23	5	1	24	5	1	25	4	1	26	3	1	**16**
27	3	1	28	3	1	29	3	1	30	3	1	31	3	1	32	4	1	33	4	1	**17**
34	4	1	35	4	1	36	4	1	37	4	1	38	4	1	39	4	1	40	4	1	**18**
41	4	1	42	4	1	43	4	1	44	4	1	45	4	1	46	4	1	47	4	1	**19**
48	4	1	49	5	1	49	6	1	50	7	1	50	8	1	49	9	1	47	10	1	**20**
48	11	1	48	12	1	49	13	1	49	14	1	49	15	1	48	16	1	47	16	1	**21**
46	16	1	45	16	1	44	16	1	43	15	1	42	16	1	42	17	1	25	60	1	**22**
26	60	1	27	60	1	28	60	1	29	59	1	30	59	1	31	58	1	32	58	1	**23**
32	57	1	33	56	1	34	56	1	35	55	1	35	54	1	37	55	1	38	55	1	**24**
39	56	1	38	57	1	37	57	1	37	58	1	38	59	1	39	58	1	40	58	1	**25**
40	57	1	41	56	1	42	55	1	43	54	1	44	53	1	45	52	1	46	51	1	**26**
47	51	1	48	51	1	47	50	1	48	49	1	49	49	1	50	49	1	51	49	1	**27**
52	49	1	52	48	1	19	40	1	19	40	1	20	39	1	20	38	1	20	37	1	**28**
19	36	1	19	35	1	17	34	1	17	33	1	17	32	1	16	31	1	16	30	1	**29**
16	29	1	16	28	1	16	27	1	14	26	1	12	26	1	11	25	1	10	25	1	**30**
9	25	1	8	24	1	7	23	1	6	23	1	5	24	1	4	24	1	4	23	1	**31**
5	22	1	5	21	1	5	20	1	6	20	1	8	20	1	8	19	1	9	19	1	**32**
10	19	1	11	19	1	12	18	1	13	17	1	15	16	1	13	15	1	13	14	1	**33**
13	13	1	13	12	1	11	11	1	9	10	1	19	40	1	19	40	1				**34**
0.31	0.31	0.31	0.31	0.51	0.51	0.31															**35**
0.2	0.51	0.31	0.04	0	0.31	0.31															**36**
0.31	0.31	0.31	0.31	0.31	0	0.31															**37**
2	2	2	2	2	2	2															**38**
2	2	2	2	2	2	2															**39**
2	2	2	2	2	2	2															**40**
2	2	2	2	0	0	0.1															**41**
0.1	0.1	0.1	0.1	0.1	0.1	0.1															**42**
0.1	0.1	0.1	0.1	0.1	0.1	0.1															**43**
0.1	0.1	0.1	0.1	0.1	0.1	0.1															**44**
0.1	0.1	0.1	0.1	0.1	0.1	0.1															**45**
0.1	0.1	0.1	0.1	0.1	0.1	0.1															**46**
0.1	0.1	0.1	0.1	0.1	0.1	0.1															**47**
0.1	0.1	0.1	0.1	0.1	0.1	0.1															**48**
0.1	0.1	0.1	0.1	0.1	0.1	3.8															**49**
3.8	3.8	3.8	3.8	3.8	3.8	3.8															**50**
3.8	3.8	3.8	3.8	3.8	3.8	3.8															**51**
3.8	3.8	3.8	3.8	3.8	3.8	3.8															**52**
3.8	3.8	3.8	3.8	3.8	3.8	3.8															**53**
3.8	3.8	3.8	3.8	3.8	3.8	3.8															**54**
3.8	3.8	0	0	0.4	0.4	0.4															**55**
0.4	0.4	0.4	0.4	0.4	0.4	0.4															**56**
0.4	0.4	0.4	0.4	0.4	0.4	0.4															**57**
0.4	0.4	0.4	0.4	0.4	0.4	0.4															**58**
0.4	0.4	0.4	0.4	0.4	0.4	0.4															**59**
0.4	0.4	0.4	0.4	0.4	0.4	0.4															**60**
0.4	0.4	0.4	0.4	0	0																**61**
	.																				**62**
	.																				**63**
	.																				**64**

Table 3-3. Example of non-point sources inputs (cont.)

			31.00				**65**
0.31	0.31	0.31	0.31	0.51	0.51	0.31	**66**
0.09	0.51	0.31	0.02	0	0.31	0.31	**67**
0.31	0.31	0.31	0.31	0.31	0	0.31	**68**
2	2	2	2	2	2	2	**69**
2	2	2	2	2	2	2	**70**
2	2	2	2	2	2	2	**71**
2	2	2	2	0	0	0.1	**72**
0.1	0.1	0.1	0.1	0.1	0.1	0.1	**73**
0.1	0.1	0.1	0.1	0.1	0.1	0.1	**74**
0.1	0.1	0.1	0.1	0.1	0.1	0.1	**75**
0.1	0.1	0.1	0.1	0.1	0.1	0.1	**76**
0.1	0.1	0.1	0.1	0.1	0.1	0.1	**77**
0.1	0.1	0.1	0.1	0.1	0.1	0.1	**78**
0.1	0.1	0.1	0.1	0.1	0.1	0.1	**79**
0.1	0.1	0.1	0.1	0.1	0.1	3.8	**80**
3.8	3.8	3.8	3.8	3.8	3.8	3.8	**81**
3.8	3.8	3.8	3.8	3.8	3.8	3.8	**82**
3.8	3.8	3.8	3.8	3.8	3.8	3.8	**83**
3.8	3.8	3.8	3.8	3.8	3.8	3.8	**84**
3.8	3.8	3.8	3.8	3.8	3.8	3.8	**85**
3.8	3.8	0	0	0.4	0.4	0.4	**86**
0.4	0.4	0.4	0.4	0.4	0.4	0.4	**87**
0.4	0.4	0.4	0.4	0.4	0.4	0.4	**88**
0.4	0.4	0.4	0.4	0.4	0.4	0.4	**89**
0.4	0.4	0.4	0.4	0.4	0.4	0.4	**90**
0.4	0.4	0.4	0.4	0.4	0.4	0.4	**91**
0.4	0.4	0.4	0.4	0	0		**92**

Comments and line numbers are in bold fonts (which are not present in the real file).

Table 3-4. Example of fall-line load inputs

2					**IFLOPT**																**1**
			0.00		**NXFLT**																**2**
0					**NOFL**	**ISYS=1**															**3**
0					**NOFL**	**ISYS=2**															**4**
0					**NOFL**	**ISYS=3**															**5**
145					**NOFL**	**ISYS=4**															**6**
4.54E-01					**SCALFL**																**7**
48	51	1	48	51	2	48	51	3	48	51	4	48	51	5	48	51	6	48	51	7	**8**
48	51	8	48	51	9	48	51	10	39	59	1	39	61	1	39	60	1	39	59	2	**9**
39	61	2	39	60	2	39	59	3	39	61	3	39	60	3	39	59	4	39	61	4	**10**
39	60	4	39	59	5	39	61	5	39	60	5	39	59	6	39	61	6	39	60	6	**11**
39	59	7	39	61	7	39	60	7	39	59	8	39	61	8	39	60	8	39	59	9	**12**
39	61	9	39	60	9	39	59	10	39	61	10	39	60	10	29	61	1	29	61	2	**13**
29	61	3	29	61	4	29	61	5	29	61	6	29	61	7	29	61	8	29	61	9	**14**
29	61	10	21	66	1	19	66	1	21	66	2	19	66	2	21	66	3	19	66	3	**15**
21	66	4	19	66	4	21	66	5	19	66	5	8	59	1	8	59	2	8	59	3	**16**
8	59	4	8	59	5	9	51	2	9	51	3	9	51	4	9	51	5	9	51	6	**17**
9	51	7	9	51	8	9	51	9	9	51	10	12	48	1	12	48	2	12	48	3	**18**
12	48	4	12	48	5	12	48	6	12	48	7	12	48	8	12	48	9	12	48	10	**19**
16	46	1	16	46	2	16	46	3	16	46	4	16	46	5	16	46	6	16	46	7	**20**
16	46	8	16	46	9	17	33	2	17	33	3	17	33	4	17	33	5	17	33	6	**21**
17	33	7	17	33	8	17	33	9	17	33	10	15	26	1	15	26	2	15	26	3	**22**
15	26	4	15	26	5	15	26	6	15	26	7	15	26	8	15	26	9	15	26	10	**23**
4	24	1	4	24	2	4	24	3	4	24	4	4	24	5	4	24	6	4	24	7	**24**
4	24	8	4	24	9	4	24	10	5	20	1	5	20	2	5	20	3	5	20	4	**25**
5	20	5	5	20	6	5	20	7	5	20	8	5	20	9	5	20	10	6	20	1	**26**
6	20	2	6	20	3	6	20	4	6	20	5	6	20	6	6	20	7	6	20	8	**27**
6	20	9	6	20	10	16	46	10	17	33	1	9	51	1							**28**
0.05	0.05	0.05	0.05	0.05	0.05	0.05															**29**
0.05	0.05	0.05	0.04	0.14	0.3	0.04															**30**
0.143	0.3	0.04	0.14	0.3	0.04	0.14															**31**
0.301	0.04	0.14	0.3	0.04	0.14	0.3															**32**
0.036	0.14	0.3	0.04	0.14	0.3	0.04															**33**
0.143	0.3	0.04	0.14	0.3	1.41	1.41															**34**
1.41	1.41	1.41	1.41	1.41	1.41	1.41															**35**
1.41	4.39	2.62	4.39	2.62	4.39	2.62															**36**
4.39	2.62	4.39	2.62	4.1	4.1	4.1															**37**
4.1	4.1	0.05	0.05	0.05	0.05	0.05															**38**
0.05	0.05	0.05	0.05	0.42	0.42	0.42															**39**
0.42	0.42	0.42	0.42	0.42	0.42	0.42															**40**
0.05	0.05	0.05	0.05	0.05	0.05	0.05															**41**
0.05	0.05	3.04	3.04	3.04	3.04	3.04															**42**
3.04	3.04	3.04	3.04	0.18	0.18	0.18															**43**
0.18	0.18	0.18	0.18	0.18	0.18	0.18															**44**
0.86	0.86	0.86	0.86	0.86	0.86	0.86															**45**
0.86	0.86	0.86	0.16	0.16	0.16	0.16															**46**
0.16	0.16	0.16	0.16	0.16	0.16	0.26															**47**
0.26	0.26	0.26	0.26	0.26	0.26	0.26															**48**
0.26	0.26	0.05	3.04	0.05																	**49**
.																					**50**
.																					**51**
.																					**52**
			31.00																		**53**
0.05	0.05	0.05	0.05	0.05	0.05	0.05															**54**
0.05	0.05	0.05	0.04	0.14	0.3	0.04															**55**
0.143	0.3	0.04	0.14	0.3	0.04	0.14															**56**
0.301	0.04	0.14	0.3	0.04	0.14	0.3															**57**
0.036	0.14	0.3	0.04	0.14	0.3	0.04															**58**
0.143	0.3	0.04	0.14	0.3	1.41	1.41															**59**
1.41	1.41	1.41	1.41	1.41	1.41	1.41															**60**
1.41	5.06	2.62	5.06	2.62	5.06	2.62															**61**
5.06	2.62	5.06	2.62	5.17	5.17	5.17															**62**
5.17	5.17	0.05	0.05	0.05	0.05	0.05															**63**
0.05	0.05	0.05	0.05	0.42	0.42	0.42															**64**
0.42	0.42	0.42	0.42	0.42	0.42	0.42															**65**
0.05	0.05	0.05	0.05	0.05	0.05	0.05															**66**
0.05	0.05	3.04	3.04	3.04	3.04	3.04															**67**
3.04	3.04	3.04	3.04	0.18	0.18	0.18															**68**
0.18	0.18	0.18	0.18	0.18	0.18	0.18															**69**
0.86	0.86	0.86	0.86	0.86	0.86	0.86															**70**
0.86	0.86	0.86	0.16	0.16	0.16	0.16															**71**
0.16	0.16	0.16	0.16	0.16	0.16	0.26															**72**
0.26	0.26	0.26	0.26	0.26	0.26	0.26															**73**
0.26	0.26	0.05	3.04	0.05																	**74**

Comments and line numbers are in bold fonts (which are not present in the real file).

Table 3-5. Example of atmospheric loading.

2		**IATMOPT**		**1**
	0.00	**NXATMT**		**2**
0		**NOATM**	**Acutal System No.**	**3**
0			**2**	**4**
0			**3**	**5**
0			**4**	**6**
0			**5**	**7**
0			**6**	**8**
1		**Valid!**	**7**	**9**
1		**SCALATM**	**7**	**10**
1.35E-08		**BATM**	**7**	**11**
1			**8**	**12**
1			**8**	**13**
1.64E-08			**8**	**14**
0			**9**	**15**
0			**10**	**16**
0			**11**	**17**
1			**12**	**18**
1			**12**	**19**
5.71E-07			**12**	**20**
1			**13**	**21**
1			**13**	**22**
7.56E-07			**13**	**23**
1			**14**	**24**
1			**14**	**25**
2.86E-06			**14**	**26**
0			**15**	**27**
0			**16**	**28**
0			**17**	**29**
0			**18**	**30**
0			**19**	**31**
1			**20**	**32**
1			**20**	**33**
5.09E-06			**20**	**34**
0			**21**	**35**
0			**22**	**36**
0			**23**	**37**
0			**24**	**38**
0			**25**	**39**
0			**26**	**40**
	31.00			**41**
1.68E-08				**42**
2.05E-08				**43**
6.98E-07				**44**
8.57E-07				**45**
3.11E-06				**46**
6.51E-06				**47**
.				**48**
.				**49**
.				**50**

Comments and line numbers are in bold fonts (which are not present in the real file).

Table 3-6. Example of open boundary conditions.

4	1			**IBCOPT, IBCPLOPT**								**1**
TIME		0.00		**NXBCT**								**2**
36				**NOBC**								**3**
	1.00E+00			**SCALBC**		**ISYS=1**						**4**
10				**NLVLS**								**5**
SLDPT	HS	0	5	10	15	20	30	40	50	75	100	**6**
	SAL	53 14 10	53 15 10	53 16 10	53 17 10	53 18 10	53 19 10	53 20 10				**7**
		53 21 10	53 22 10	53 23 10	53 24 10	53 25 10	53 26 10	53 27 10				**8**
		53 28 10	53 29 10	53 30 10	53 31 10	53 32 10	53 33 10	53 34 10				**9**
		53 35 10	53 36 10	53 37 10	53 38 10	53 39 10	53 40 10	53 41 10				**10**
		53 42 10	53 43 10	53 44 10	53 45 10	53 46 10	53 47 10	53 48 10				**11**
		53 49 10										**12**
	SAL	31.988	32.012	32.065	32.154	32.212	32.282	32.342	32.358	32.455	32.492	**13**
		32.002	32.037	32.084	32.099	32.231	32.315	32.362	32.402	32.492	32.531	**14**
		31.991	32.024	32.042	32.084	32.189	32.298	32.372	32.417	32.494	32.550	**15**
		31.978	32.011	32.031	32.080	32.178	32.300	32.367	32.407	32.500	32.540	**16**
		31.890	31.947	31.995	31.990	32.074	32.251	32.352	32.306	32.475	32.528	**17**
		31.956	31.990	32.020	32.055	32.154	32.290	32.367	32.397	32.492	32.537	**18**
		31.953	31.988	32.027	32.056	32.213	32.301	32.358	32.375	32.471	32.522	**19**
		32.018	32.063	32.115	32.156	32.214	32.323	32.426	32.430	32.515	32.614	**20**
		31.991	32.030	32.089	32.158	32.205	32.272	32.356	32.350	32.443	32.477	**21**
		31.965	31.989	32.048	32.129	32.152	32.247	32.327	32.303	32.396	32.463	**22**
		31.991	32.019	32.083	32.104	32.225	32.278	32.339	32.358	32.448	32.494	**23**
		31.839	31.876	31.974	32.027	32.116	32.241	32.312	32.328	32.430	32.483	**24**
		31.971	32.029	32.130	32.154	32.213	32.299	32.406	32.410	32.538	32.590	**25**
		31.933	31.990	32.051	32.097	32.129	32.288	32.350	32.394	32.519	32.579	**26**
		31.999	32.033	32.089	32.114	32.164	32.311	32.407	32.429	32.548	32.649	**27**
		31.957	31.981	32.062	32.102	32.154	32.301	32.374	32.398	32.536	32.637	**28**
		31.920	31.943	31.984	32.084	32.131	32.294	32.357	32.396	32.520	32.593	**29**
		32.022	31.965	32.024	32.147	32.196	32.350	32.437	32.451	32.588	32.661	**30**
		32.053	32.061	32.105	32.183	32.238	32.345	32.442	32.456	32.575	32.682	**31**
		32.069	32.019	32.050	32.162	32.229	32.356	32.459	32.461	32.557	32.661	**32**
		32.036	32.010	32.060	32.190	32.254	32.333	32.441	32.505	32.608	32.699	**33**
		32.147	32.137	32.160	32.206	32.209	32.352	32.495	32.453	32.661	32.746	**34**
		32.094	32.065	32.165	32.191	32.225	32.345	32.471	32.471	32.624	32.708	**35**
		32.043	32.055	32.100	32.215	32.274	32.335	32.437	32.501	32.602	32.643	**36**
		31.856	31.976	32.004	32.124	32.257	32.296	32.455	32.461	32.572	32.669	**37**
		31.979	32.080	32.044	32.155	32.222	32.381	32.478	32.526	32.714	32.804	**38**
		32.104	32.120	32.171	32.180	32.196	32.414	32.498	32.468	32.673	32.775	**39**
		32.021	31.967	32.134	32.184	32.237	32.362	32.480	32.536	32.709	32.738	**40**
		31.877	31.981	32.007	32.146	32.240	32.374	32.448	32.582	32.722	32.816	**41**
		32.043	32.023	32.140	32.226	32.266	32.298	32.496	32.540	32.733	32.835	**42**
		31.971	31.884	31.913	31.966	32.152	32.259	32.454	32.450	32.623	32.715	**43**
		31.963	31.986	32.111	32.167	32.245	32.272	32.486	32.512	32.718	32.767	**44**
		32.075	31.971	32.162	32.236	32.264	32.391	32.540	32.589	32.801	32.858	**45**
		31.920	31.940	32.175	32.223	32.297	32.406	32.484	32.602	32.722	32.762	**46**
		31.810	31.868	31.894	31.917	32.224	32.296	32.412	32.509	32.554	32.727	**47**
		31.928	32.133	32.154	32.250	32.264	32.420	32.518	32.658	32.717	32.770	**48**
		.										**49**
		.										**50**
		.										**51**
TIME		15.00										**52**
	SAL	32.252	32.244	32.201	32.239	32.288	32.357	32.410	32.452	32.533	32.562	**53**
		32.204	32.186	32.221	32.250	32.350	32.380	32.460	32.497	32.572	32.613	**54**
		32.118	32.202	32.227	32.258	32.307	32.395	32.467	32.517	32.606	32.653	**55**
		32.132	32.177	32.217	32.253	32.305	32.401	32.467	32.516	32.601	32.654	**56**
		.										**57**
		.										**58**
		.										**59**

Comments and line numbers are in bold fonts (which are not present in the real file).

Table 3-7. Control options for nutrient inputs.

Table	Parameter	Description
Table 3-2	IPSOPT	Input option, 1--constant, 2--time-variable input
	NXPST	Time of the record
	NOPS(ISYS)	Number of segments for each system
	SCALPS(ISYS)	Scale factor for each system
	IPS(J, I, ISYS)	Segments for point sources (I=1, NOPS)
	BPS (I, ISYS)	Values of the point sources (I=1,NOPS)
Table 3-3	INPSOPT	Input option, 1--constant, 2--time-variable input
	NXNPST	Time of the record
	NONPS	Number of segments
	SCALNPS(ISYS)	Scale factor for each system
	INPS(J, I, ISYS)	Segments for non-point sources (I=1, NONPS)
	BNPS(I, ISYS)	Values of the non-point sources (I=1, NONPS)
Table 3-4	IFLOPT	Input option, 1--constant, 2--time-variable input
	NXFLT	Time of the record
	NOFL(ISYS)	Number of segments for each system
	SCALFL(ISYS)	Scale factor for each system
	IFL(J, I, ISYS)	Segments for fall-line sources (I=1, NOFL)
	BFL(I, ISYS)	Values of the fall-line sources (I=1, NOFL)
Table 3-5	IATMOPT	Input option, 1--constant, 2--time-variable input
	NXATMT	Time of the record
	NOATM(ISYS)	Number of segments for each system, 0---no input, 1-yes
	SCALATM(ISYS)	Scale factor for each system
	BATM(ISYS)	Values of the atmospheric loads
Table 3-6	IBCOPT	Input option, 1--constant, sigma level, 2--time-variable input, sigma level, 3--constant, standard level, 4--time-variable, standard level
	IBCPLOPT	Interpolation option, 0--step function, 1--linear interpolation
	NXBCT	Time of the record
	NOBC(ISYS)	Number of segments for each system
	SCALBC(ISYS)	Scale factor for each system
	NLVLS	Number of the standard depths (when IBCOPT=3 or 4)
	SLDEPTH(I, ISYS)	Standard level depths for each system (I=1, NLVLS) (when IBCOPT = 3 or 4)
	IBC(J, I, ISYS)	Segments for boundary inputs(I=1, NOBC)
	BBC(I, ISYS)	Values of the boundary inputs (I=1, NOBC)
	NOBCSL(I, ISYS)	Temporal variable, number of standard for each system at each segment (I=1, NOBC) (when IBCOPT=3 or 4)
	SLBC(J)	Temporal variable to input biomass at given standard level (J=1, NOBCSL) (when IBCOPT=3 or 4)

If not specified, ISYS ranges 1-NOSYS, and J=1, 2, 3 representing column, row and layer, respectively.

Table 3-8. Example of model parameter inputs for the water column.

	6								**1**
	0.5	1	1	1	1	1			**2**
KL									**3**
	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	**4**
	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	**5**
	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	**6**
	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	**7**
	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	**8**
	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	**9**
	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00	2.00E+00			**10**
	.								**11**
	.								**12**
	.								**13**
VSNET1									**14**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**15**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**16**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**17**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**18**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**19**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**20**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00			**21**
	.								**22**
	.								**23**
	.								**24**
VSNET2									**25**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**26**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**27**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**28**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**29**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**30**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**31**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00			**32**
	.								**33**
	.								**34**
	.								**35**
VSNET3									**36**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**37**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**38**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**39**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**40**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**41**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**42**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00			**43**
	.								**44**
	.								**45**
	.								**46**
VSNET4									**47**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**48**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**49**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**50**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**51**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**52**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	**53**
	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00			**54**
	.								**55**
	.								**56**
	.								**57**
KEBASE									**58**
	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	**59**
	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	**60**
	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	**61**
	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	**62**
	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	**63**
	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	**64**
	0.22	0.22	0.22	0.22	0.22	0.22			**65**
	.								**66**
	.								**67**
	.								**68**

Table 3-8. Example of model parameter inputs for the water column. (Continued)

	0								**69**
	134	number	of	constants	1999				**70**
TOPT1	8	K1TX1	0.004	K1TX2	0.006	GPRE1	2.5	GPRO1	**71**
IS1	0	KMN1	0.01	KMP1	0.001	KMS1	0.02	K1RB	**72**
K1RG	0.28	K1GZC	0.1	K1GZT	1.1	FSC1	0.1	CCHL1	**73**
WCPR1	40	WCNR1	5	WCSR1	2.5	QF1	0.85	TOPT2	**74**
K2TX1	0.004	K2TX2	0.006	GPRE2	3	GPRO2	0.28	IS2	**75**
KMN2	0.01	KMP2	0.001	KMS2	0.005	K2RB	0.06	K2RG	**76**
K2GZC	0.1	K2GZT	1.1	FSC2	0.1	CCHL2	65	WCPR2	**77**
WCNR2	5.67	WCSR2	7	QF2	0.85	XKC	0.017	KMPHY	**78**
FRPOP	0.15	FLPOP	0.3	FRDOP	0.1	FLDOP	0.15	FPO4	**79**
FRPON	0.15	FLPON	0.325	FRDON	0.15	FLDON	0.175	FNH3	**80**
FRPOC	0.15	FLPOC	0.35	FRDOC	0.1	FLDOC	0.4	K46C	**81**
K46T	1.08	K57C	0.05	K57T	1.08	K68C	0.01	K68T	**82**
K78C	0.1	K78T	1.08	K911C	0.008	K911T	1.08	1012C	**83**
1012T	1.08	1113C	0.008	1113T	1.08	1213C	0.05	1213T	**84**
1314C	0.1	1314T	1.08	KNIT	1	K140C	0.05	K140T	**85**
KNO3	0.1	1516C	0.08	1516T	1.08	1719C	0.01	1719T	**86**
1820C	0.07	1820T	1.08	K190C	0.008	K190T	1.08	K200C	**87**
K200T	1.08	KLDOC	0.1	KDOC	0.2	K210C	0.3	K210T	**88**
FLOCX	0.1	K220C	0.15	K220T	1.08	K23OC	0.15	K23OT	**89**
KO2EQ	0.1	KAT	1.024	VSBS1	0.5	VSNT1	1	VSBS2	**90**
VSNT2	0.7	VST	1.027	VSPOM	1	VSTAM	0.125	VSPMT	**91**
KAPO4	6	KADSI	6	VSSDT	1.027	DTAMX	1.5	DOTAM	**92**
JTAMC	0	JTAMT	1.027	KTAM	1	TOPT3	14	K3TX1	**93**
K3TX2	0.006	GPRE3	2.5	GPRO3	0.28	IS3	0	KMN3	**94**
KMP3	0.001	KMS3	0.04	K3RB	0.03	K3RG	0.28	K3GZC	**95**
K3GZT	1.1	FSC3	0.1	CCHL3	15	WCPR3	40	WCNR3	**96**
WCSR3	2.5	QF3	0.85	VSBS3	0.3	VSNT3	1		**97**
	3	0	no	plf					**98**
I_TOT	368	TOTAL	DAILY	RADIATIOI	Langleys				**99**
	200	0	200	1	32	2	68	3	**100**
	42	4	23	5	204	6	201	7	**101**
	216	8	227	9	208	10	208	11	**102**
	80	12	93	13	228	14	186	15	**103**
	230	16	239	17	34	18	332	19	**104**
	250	20	246	21	114	22	228	23	**105**
	237	24	265	25	249	26	124	27	**106**
	112	28	251	29	268	30	276	31	**107**
	285	32	286	33	179	34	259	35	**108**
	260	36	33	37	99	38	317	39	**109**
	.								**110**
	.								**111**
	.								**112**
	87	364	140	365	140	366	140	999	**113**
F_DAY	368	FRACTIOI	OF	DAYLIGHT					**114**
	0.3743	0	0.3749	1	0.3754	2	0.376	3	**115**
	0.3767	4	0.3774	5	0.3781	6	0.3789	7	**116**
	0.3797	8	0.3805	9	0.3814	10	0.3823	11	**117**
	0.3833	12	0.3843	13	0.3853	14	0.3864	15	**118**
	0.3875	16	0.3886	17	0.3898	18	0.391	19	**119**
	0.3922	20	0.3935	21	0.3948	22	0.3961	23	**120**
	0.3975	24	0.3989	25	0.4003	26	0.4017	27	**121**
	0.4032	28	0.4047	29	0.4062	30	0.4077	31	**122**
	0.4093	32	0.4109	33	0.4125	34	0.4141	35	**123**
	0.4158	36	0.4174	37	0.4191	38	0.4208	39	**124**
	.								**125**
	.								**126**
	.								**127**
	0.3739	364	0.3743	365	0.3749	366	0.3754	999	**128**
WIND	368	(m/s)							**129**
	9.1	0	9.1	1	3.7	2	2.5	3	**130**
	2.9	4	7.4	5	8.1	6	11.7	7	**131**
	11.9	8	10	9	7.7	10	8.1	11	**132**
	7.3	12	7.7	13	11.3	14	8.3	15	**133**
	13.7	16	13.2	17	5.2	18	10.8	19	**134**
	11.5	20	8.1	21	6	22	11.7	23	**135**
	10	24	10.9	25	7.7	26	6	27	**136**
	6.7	28	12.2	29	11.9	30	9.4	31	**137**
	9.4	32	5.5	33	4.8	34	9.7	35	**138**
	9.5	36	5.1	37	5.1	38	12.5	39	**139**
	.								**140**
	.								**141**
	.								**142**
	8.8	364	4.5	365	4.5	366	2	999	**143**

Table 3-9. Run controls input file for the 2004 BEMwq simulation.

0 1 0 1 1 1 1 0 1 0	**1**
Massachusetts May Fine Grid Model - Calibration	**2**
END	**3**
SAL PHYT1 PHYT RPOP LPOP RDOP LDOP DIP RPON LPON	**4**
RDON LDON NH3 NO23 SIU SI RPOC LPOC RDOC LDOC	**5**
REDOC EXDOC O2EQ DO TAM PHYT3	**6**
TIME-VARIABLE SIMULATION	**7**
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0	**8**
3 2 128	**9**
18 11 1 18 11 10 38 11 1 38 11 10 15 18 1 15 18 10	**10**
40 19 1 40 19 10 19 30 1 19 30 10 26 30 1 26 30 10	**11**
31 29 1 31 29 10 40 31 1 40 31 10 23 35 1 23 35 10	**12**
27 35 1 27 35 10 32 35 1 32 35 10 43 33 1 43 33 10	**13**
24 40 1 24 40 10 22 44 1 22 44 10 28 41 1 28 41 10	**14**
33 39 1 33 39 10 37 37 1 37 37 10 31 55 1 31 55 10	**15**
39 42 1 39 42 10 39 51 1 39 51 10 41 48 1 41 48 10	**16**
43 44 1 43 44 10 20 54 1 20 54 10 25 53 1 25 53 10	**17**
21 49 1 21 49 10 51 47 1 51 47 10 52 42 1 52 42 10	**18**
46 36 1 46 36 10 41 21 1 41 21 10 18 59 1 18 59 10	**19**
17 52 1 17 52 10 29 11 1 29 11 10 39 16 1 39 16 10	**20**
30 53 1 30 53 10 32 51 1 32 51 10 35 49 1 35 49 10	**21**
37 48 1 37 48 10 35 46 1 35 46 10 33 44 1 33 44 10	**22**
32 42 1 32 42 10 29 44 1 29 44 10 27 45 1 27 45 10	**23**
24 47 1 24 47 10 26 49 1 26 49 10 28 51 1 28 51 10	**24**
30 50 1 30 50 10 32 49 1 32 49 10 34 47 1 34 47 10	**25**
33 46 1 33 46 10 31 45 1 31 45 10 29 46 1 29 46 10	**26**
28 47 1 28 47 10 29 49 1 29 49 10 31 47 1 31 47 10	**27**
21 65 1 21 65 10 19 63 1 19 63 10 18 59 1 18 59 10	**28**
18 55 1 18 55 10 21 54 1 21 54 10 12 60 1 12 60 10	**29**
11 52 1 11 52 10 14 54 1 14 54 10 16 51 1 16 51 10	**30**
15 48 1 15 48 10	**31**
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	**32**
14 14 10 20 20 10 30 30 1 40 40 10 40 10 1 15 52 1	**33**
4 0 0 expl smol, no neg, sigma corr	**34**
1 0 0 time warp factor	**35**
1 nodelt	**36**
0.002875 365	**37**
13700 1 2 1 nobrk,icollopt,cycleopt,wetgridopt	**38**
0 0.0431 0.0863	**39**
1 1 1 1 scale factor of Q, RX, RY, RZ	**40**
../hydro_2004/gcm_tranWQf2004.1	**41**
../in_2004/bcf.2004.2wk 0	**42**
../in_2004/ps.2004.wk 0	**43**
../in_2004/nps.2004 0	**44**
../in_2004/model.fl2004 0	**45**
../in_2004/atmos2004.load 0	**46**
../in_2004/model.pcv.2004 0	**47**
../in_2004/bin2004.ic 1	**48**
stability 5000 3000 3000 1000 100 20 50	**49**
100 500 100 1000 500 1000 1000	**50**
1000 1000 1000 1000 2000 5000 3000	**51**
1000 3000 5000 5000 5000	**52**
accuracy 1 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001	**53**
0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001	**54**
0.0001 0.0001 0.0001 0.0001 0.0001 0.0001 0.0001	**55**
0.0001 0.0001 0.0001 0.0001 0.0001 0.0001	**56**
1 1 averaging global detailed 0-no 1-yes	**57**
../in_2004/sed.inp.newic	**58**
../hydro_2004/gcm_tranWQf2004.2	**59**
../hydro_2004/gcm_tranWQf2004.3	**60**
../hydro_2004/gcm_tranWQf2004.4	**61**
../hydro_2004/gcm_tranWQf2004.5	**62**
../hydro_2004/gcm_tranWQf2004.6	**63**
../hydro_2004/gcm_tranWQf2004.7	**64**
../hydro_2004/gcm_tranWQf2004.8	**65**
../hydro_2004/gcm_tranWQf2004.9	**66**
../hydro_2004/gcm_tranWQf2004.10	**67**
../hydro_2004/gcm_tranWQf2004.11	**68**
../hydro_2004/gcm_tranWQf2004.12	**69**
	70
1 LYR 1	**71**
1 LYR 10	**72**

Table 3-10. Example of sediment inputs.

0	0	0	!	isedprnt	-----	print	control	**1**
0	0	0	0	0	0	0	0	**2**
0	0	0	0	0	0	0	0	**3**
0	0	0	0	0	0	0	0	**4**
0	0	0	0	0	0	0	0	**5**
0	0	0	0	0	0	0	0	**6**
0	0	0	0	0	0	0	0	**7**
0	0	0	0	0	0			**8**
.								**9**
.								**10**
.								**11**
1.00E+00								**12**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**13**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**14**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**15**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**16**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**17**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**18**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			**19**
.								**20**
.								**21**
.								**22**
0.0018								**23**
0								**24**
0.65	0.2	0.15						**25**
0.65	0.2	0.15						**26**
0.65	0.2	0.15						**27**
0.65	0.2	0.15						**28**
0.65	0.25	0.1						**29**
0.65	0.25	0.1						**30**
0.65	0.25	0.1						**31**
0.65	0.25	0.1						**32**
0.65	0.2	0.15						**33**
0.65	0.2	0.15						**34**
0.65	0.2	0.15						**35**
0.65	0.2	0.15						**36**
0.035	1.1	0.0018	1.15	0.000001	1.17			**37**
0.035	1.1	0.0018	1.15	0.000001	1.17			**38**
0.035	1.1	0.0018	1.15	0.000001	1.17			**39**
0.5	1.1	!	ksi,	thtasi				**40**
1.00E+00	sedimentat							**41**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**42**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**43**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**44**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**45**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**46**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**47**
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			**48**
.								**49**
.								**50**
.								**51**
0.5	0.5	1.15	1.15	!	m1,	m2,thtaDp,thtaDd		**52**
0.001	1.08							**53**
0.131	1	1.12	728	1.13	0.74			**54**
0.2	1.08							**55**
0.1	0.25	1.08						**56**
0.1	0.25	1.08						**57**
0.2	0.4	100	100	1.08	4			**58**
40000	10	100	0.5	1.1	5.00E+07	2	50	**59**
20	20	2	4					**60**
10	0.03	0	0					**61**
0.2	1.08							**62**

Table 3-11. Options for run controls and sediment model parameters.

Table	Line	Description	Reference in RCA 3.0 (page #, section)
Table 3-8			Group L, Section 2
	line 1-68	2-D model parameters	p86, L1-L4
	line 69	3-D model parameters	p87-88, L5-L8
	line 70-97	Constants	p88-89, L9-10
	line 98-143	Time-variable function	p89-90, L11-13
Table 3-9			Group A-F, Section 2
	line 1	Model descriptor CYCLE, MODEL, ISER, IRUN, (LIST(I), I=1,5), IDIADGT	p18-19, A1
	line 8	Simulation bypass options for each system	p20-21, A4
	line 9	Model print options PRNTG, PRNTD, NDMPS	
	line 10-31	Segments for detailed dumps	
	line 32	Detailed dump bypass options for each system	
	line 33	Segments for intermediate dump to standard output	
	line 34	Integration Procedure Options INTGRTYP, NEGSLN, SLCOPT	p22-24, B1-B2
	line 35	Time warp scale factors	p25-26, B3
	line 36	Number of time step (NSTEP)	P26, B4
	line 37	Time step and time break for switching time step STEP(I), TBRK(I), I=1,NSTEP	P26, B4
	line 38	Hydrodynamic file input options NOHYD, ICOLLOPT, HYDCYCOPT, LNDWTROPT	p32-33, C1
	line 40	Advection and dispersion scale factors SCALQ, SCALX, SCALY, SCALZ	p33-34, C3
	line 41-48	Input files and options (0—Binary, 1—ASCII)	
	line 49-52	Stability criteria	p41, E1
	line 53-56	Minimum conc. for numerical integration	p41, E2
	line 58-69	More input files	
	line 71-72	System dumps	p42, F1
Table 3-10			Group P, Appendix A
	line 1	Print options	p72, P1
	line 2-11	Sediment depths	p72, P2
	line 12-22	Sediment initial conditions	p73-74, P3
	line 23	Temperature diffusion coefficient (DIFFT)	p74, P4
	line 24	SALTSW	p74, P4
	line 25-36	G component fractions	p75-77, P4

Table	Line	Description	Reference in RCA 3.0 (page #, section)
	line 37	KPDIAG(1), DPTHTA(1), KPDIAG(2), DPTHTA(2), KPDIAG(3), DPTHTA(3)	p78, P4
	line 38	KNDIAG(1), DNTHTA(1), KNDIAG(2), DNTHTA(2), KNDIAG(3), DNTHTA(3)	p78, P4
	line 39	KCDIAG(1), DCTHTA(1), KCDIAG(2), DCTHTA(2), KCDIAG(3), DCTHTA(3)	p78, P4
	line 40	KSI, THTASI	p74-78, P4
Table 3-10 cont'd	line 41-51	Sedimentation and particle mixing rate	p78-79, P5
	line 52	M1, M2, THTADp, THTADd	p79, P6
	line 53	Dd0, THTAd0	p81, P6
	line 54	KappNH4S, PIENH4, THTNH4S, KMNH4, THTKNNH4, KMNH4O2	p81, P6
	line 55	KAPPNH4F, THTANH4F	p82, P6
	line 56	KAPP1NO3S, K2NO3S, THTANO3S	p82, P6
	line 57	KAPP1NO3F, K2NO3F, THTANO3F	p82, P6
	line 58	KAPPD1, KAPPP1, PIE1S, PIE2S, THTPD1, KMHSO2	p83, P6
	line 59	CSISAT, PIE1SI, PIE2SI, KSI, THTASI, KMPSI, OCRITSI, JSIDETR	p83, P6
	line 60	PIE1PO4M, PIE1PO4N, O2CRIT, KMO2DP	p85, P6
	line 61	TEMPBNTH, KBNTHSTR, KLBNTH, DPMIN	p87, P6
	line 62	KAPPCH4, THTACH4 (last 3 parameters not in RCA2.0)	p87, P6

4. MODEL OUTPUT

There are several pre-defined model outputs, which include three files for time-history of results (1) global dumps of selected variables over entire model domain (RCAF11), (2) detailed dumps including key rates of biogeochemical processes at selected segments (RCAF13), and (3) concentrations and fluxes for the sediment subroutine (RCAF14). Two other files store the bypass options for global dumps and detailed dumps (RCAF10 and RCAF12). The final results of the simulations will be stored in two separate files to be used as initial conditions for subsequent simulations (RCAFIC and RCAFICSED). Users can always generate their own outputs. A list of these files is shown in Table 4-1. We will only briefly describe the three time-history files below. More detailed descriptions of these files can be found in RCA3.0 user manual (Appendix D, HydroQual 2004). Unlike RCA 3.0, no pre-defined files are designated for the mass balance in BEMwq.

4.1 Global dumps

RCAF11 stores model results of selected model variables for the entire domain at selected time step. The model variables are not limited to the 26 model systems. For example, in the current BEMwq, the model also outputs computed gross primary productivity.

4.2 Detailed dumps at selected segments

RCAF13 stores the detailed model results at selected segments as specified in run control file (Table 3-9). These results include concentrations of model variables and modeled rates for biogeochemical processes.

4.3 Sediment

RCAF14 stores fluxes and concentrations from sediment submodel. Only results at water segments are exported.

Table 4-1. Model Output Files

Name	Type	Description
stdout	ASCII	standard output
RCAF10	binary	the system bypass options and times at which the grid-wide dumps were generated
RCAF11	binary	a time-history of the grid-wide or global dumps for all state-variables
RCAF12	binary	system bypass options, dump variable names and times at which the detailed dumps were generated (for selected segments)
RCAF13	binary	a more detailed time-history dump for selected segments and selected parameters
RCAFIC	binary	final results to be used as initial conditions for subsequent simulations
RCAF14	binary	the concentrations and fluxes computed by the sediment nutrient flux subroutines
RCAFICSED	binary	final results to be used as initial conditions for sediment component in subsequent simulations

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Appendix A. Model kinetic equations for nitrogen cycle.

Here we outline the biogeochemical processes simulated in the water quality model (BEMwq). For convenience notations and descriptions of model parameters are listed in Appendices A and C and will not be described below. More detailed descriptions of these formulations can be found in *HydroQual and Normandeau* (1995).

1) Phytoplankton Growth

Phytoplankton (P_c) growth is determined by net growth (μ), sinking loss (k_{sp}) and grazing loss (k_{grz}),

$$G_p = \left(\mu - k_{sp}(T) - k_{grz}(T)\right)P_C \qquad \text{(A1)}$$

where T denotes the ambient water temperature.

The specific net growth rate μ of phytoplankton is defined as

$$\mu = \left(\mu_{\max} G_T(T) - k_{RB}\right)G_N(N) \qquad \text{(A2)}$$

where $\mu_{\max}$ is nutrient-saturated growth rate, $G_T(T)$ is temperature correction factor, and $G_N(N)$ is nutrient limitation factor.

Temperature dependence of phytoplankton growth is determined by

$$G_T(T) = \begin{cases} \exp\left(-\beta_1\left(T - T_{OPT}\right)^2\right) & T \le T_{OPT} \\ \exp\left(-\beta_2\left(T_{OPT} - T\right)^2\right) & T \ge T_{OPT} \end{cases} \qquad \text{(A3)}$$

Nutrient uptake follows the Liebig's law with the limitation of individual nutrient determined by Michaelis-Menten kinetics,

$$G_N(N) = \min\left(\frac{DIN}{k_N + DIN}, \frac{DIP}{k_P + DIP}, \frac{Si}{k_{Si} + Si}\right) \qquad \text{(A4)}$$

where DIN is total dissolved inorganic nitrogen, DIP is total dissolved inorganic phosphorus and Si is dissolved silicic acid (silicate).

Nutrient saturated growth rate ($\mu_{\max}$) is based on the balance growth model developed by *Laws and Chalup* [1990]

$$\mu_{\max} = \frac{G_{pre}(1-k_{RG})(1-f_{SC})I)}{G_{pre}/G_{pr0} + I(1+G_{pre}/(I_S G_{pr0}))} \quad \text{(A5)}$$

where $I(z,t)$ is solar radiation (mol quanta m-2 d-1), and Is is the radiation when photosynthetic rate reaches 50% of the maximum photosynthetic rate (when I=0).

Chlorophyll to carbon ratio is also following the formulation by *Laws and Chalup* [1990]

$$a_{ChlC} = \frac{1-(1-QF)(1-\mu/\mu_{\max}) - f_{SC} - (\mu + k_{RB})(1-k_{RG})G_{pre}}{W_{CChl}} \quad \text{(A6)}$$

and phytoplankton endogenous respiration is determined by

$$k_{PR} = \frac{k_{RB} + k_{RG}\mu}{1-k_{RG}} \quad \text{(A7)}$$

The total primary productivity is determined by

$$GPP = (\mu + k_{PR})P_c \quad \text{(A8)}$$

and total respiration and grazing is

$$Loss = (k_{PR} + k_{grz}(T))P_c \quad \text{(A9)}$$

2) Light

Light attenuation accounts for background attenuation and phytoplankton self-shading,

$$k_{ext} = k_{base} + k_c a_{ChlC} P_{tot} \quad \text{(A10)}$$

where Ptot is total phytoplankton biomass of the three phytoplankton groups. Thus the solar radiation at depth z (upward positive with origin at sea surface) is,

$$I(z,t) = I_{surf}(t)\exp\left(\int_0^z k_{ext}dz\right) \quad \text{(A11)}$$

where $I_{surf}(t)$ is surface solar radiation that can be calculated from daily mean solar radiation (Itot),

$$I_{surf}(t) = \frac{I_{tot}}{0.635 f}\sin\left(\frac{\pi(t-t_{sunrise})}{f}\right) \quad \text{(A12)}$$

Then I_s is determined by the average light level for the previous three days,

$$I_s = (I_{tot_{n-3}} + I_{tot_{n-2}} + I_{tot_{n-1}})/3 \quad \text{(A13)}$$

3) Algal settling [*Bienfang et al.*, 1982; *Culver and Smith*, 1989],

$$k_{sp}(T) = (V_b + V_N(1-G_N(N)))\theta_{sp}^{(T-20)}/H \quad \text{(A14)}$$

4) Zooplankton grazing

$$k_{grz}(T) = k_{grz0}\theta_{grz}^{(T-20)} \quad \text{(A15)}$$

5) Hydrolysis of particulate organic matter to dissolved organic nitrogen

$$R_{LPON} = k_{LPON}\theta_{LPON}^{T-20} \frac{P_{tot}}{K_{mp} + P_{tot}} LPON \quad \text{(A16a)}$$

$$R_{RPON} = k_{RPON}\theta_{RPON}^{T-20} \frac{P_{tot}}{K_{mp} + P_{tot}} RPON \quad \text{(A16b)}$$

6) Mineralization of dissolved organic nitrogen to ammonia

$$R_{LDON} = k_{LDON}\theta_{LDON}^{T-20} \frac{P_{tot}}{K_{mp} + P_{tot}} LDON \quad \text{(A17a)}$$

$$R_{RDON} = k_{RDON}\theta_{RDON}^{T-20} \frac{P_{tot}}{K_{mp} + P_{tot}} RDON \quad \text{(A17b)}$$

7) Nitrification

$$R_{Nit} = k_{Nit}\theta_{Nit}^{T-20} \frac{DO}{k_{Nit\_DO} + DO} NH_3 \quad \text{(A18)}$$

8) Denitrification

$$R_{Denit} = k_{Denit}\theta_{Denit}^{T-20} \frac{k_{Denit\_DO}}{k_{Denit\_DO} + DO} NO_3 \quad \text{(A19)}$$

9) Exudation of total primary productivity (*GPP*) into dissolved organic carbon

$$R_{exud} = a_{NC} f_{ExDOC} GPP \quad \text{(A20)}$$

10) Nitrogen to carbon ratio

$$a_{NC} = \frac{QF + (1 - QF)\,\mu/\mu_{\max}}{W_{CN}} \quad \text{(A21)}$$

11) 17) Settling of particulate organic nitrogen

$$k_{PON}(T) = \frac{V_{PON}}{H}\theta_{PON}^{T-20} \quad \text{(A22)}$$

Appendix B. Model parameters for the nitrogen cycle.

Notation	Description	Values
Diatoms (winter/spring group) growth, carbon to nitrogen ratios and carbon to chlorophyll ratios		
T_{opt1}	Optimal growth temperature	8 ºC
β_{11}	Temperature correction coefficient on growth rate	0.004 $(ºC)^{-2}$
β_{21}	Temperature correction coefficient on growth rate	0.006 $(ºC)^{-2}$
G_{pre1}	Gross photosynthetic rate	2.5 day^{-1}
G_{pr01}	Nutrient-saturated gross photosynthetic rate per unit light intensity	0.28 m^2(mol quanta)$^{-1}$
k_{N1}	Half saturation constant for nitrogen uptake	0.01 mg N l^{-1}
k_{RB1}	Basal respiration rate	0.03 day^{-1}
k_{RG1}	Growth-rate-dependent respiration coefficient	0.28
k_{grz01}	Mortality rate due to grazing	0.1 day^{-1}
θ_{grz1}	Temperature dependent coefficient for grazing	1.1
f_{sc1}	Fraction of C allocated to structural purposes	0.1
W_{CChl1}	Nutrient-saturated carbon to chlorophyll ratio	40 mgC (mgChl a)$^{-1}$
QF_1	Quotient of nutrient-limited N:C ratio	0.85
W_{CN1}	Nutrient-saturated carbon to nitrogen ratio	5.0 mgC (mgN)$^{-1}$
Summer group growth, carbon to nitrogen ratios and carbon to chlorophyll ratios		
T_{opt2}	Optimal growth temperature	18 ºC
β_{12}	Temperature correction coefficient on growth rate	0.004 $(ºC)^{-2}$
β_{22}	Temperature correction coefficient on growth rate	0.006 $(ºC)^{-2}$
G_{pre2}	Gross photosynthetic rate	3.0 day^{-1}
G_{pr02}	Nutrient-saturated gross photosynthetic rate per unit light intensity	0.28 m^2(mol quanta)$^{-1}$
k_{N2}	Half saturation constant for nitrogen uptake	0.01 mg N l^{-1}
k_{RB2}	Basal respiration rate	0.036 day^{-1}
k_{RG2}	Growth-rate-dependent respiration coefficient	0.28
k_{grz02}	Mortality rate due to grazing	0.1 day^{-1}
θ_{grz2}	Temperature dependent coefficient for grazing	1.1
f_{sc2}	Fraction of C allocated to structural purposes	0.1
W_{CChl2}	Carbon to chlorophyll ratio	65 mgC (mgChl a)$^{-1}$
QF_2	Quotient of nutrient-limited N:C ratio	0.85
W_{CN2}	Nutrient-saturated carbon to nitrogen ratio	5.67 mgC (mgN)$^{-1}$
Fall group growth, carbon to nitrogen ratios and carbon to chlorophyll ratios		
T_{opt3}	Optimal growth temperature	14 ºC
β_{13}	Temperature correction coefficient on growth rate	0.004 $(ºC)^{-2}$
β_{23}	Temperature correction coefficient on growth rate	0.006 $(ºC)^{-2}$
G_{pre3}	Gross photosynthetic rate	2.5 day^{-1}
G_{pr03}	Nutrient-saturated gross photosynthetic rate per unit light intensity	0.28 m^2(mol quanta)$^{-1}$
k_{N3}	Half saturation constant for nitrogen uptake	0.005 mg N l^{-1}
k_{RB3}	Basal respiration rate	0.03 day^{-1}
k_{RG3}	Growth-rate-dependent respiration coefficient	0.28
k_{grz03}	Mortality rate due to grazing	0.1 day^{-1}
θ_{grz3}	Temperature dependent coefficient for grazing	1.1
f_{sc3}	Fraction of C allocated to structural purposes	0.1

W_{CChl3}	Carbon to chlorophyll ratio	15 mgC (mgChl a)$^{-1}$
QF_3	Quotient of nutrient-limited N:C ratio	0.85
W_{CN3}	Nutrient-saturated carbon to nitrogen ratio	5.67 mgC (mgN)$^{-1}$

<u>Light attenuation</u>

k_{base}	Background light attenuation coefficient (2-D parameter)	0.16~0.6 m^{-1}
k_c	Chlorophyll self-shading coefficient	0.017 m^2(mg chl)$^{-1}$

<u>Nitrogen regeneration, nitrification and denitrification</u>

k_{mp}	Half saturation constant for nitrogen regeneration	0.05 mgC l^{-1}
k_{RPON}	Hydrolysis rate of RPON to RDON at 20ºC	0.008 day^{-1}
θ_{RPON}	Temperature coefficient for RPON hydrolysis	1.08
k_{LPON}	Hydrolysis rate of LPON to LDON at 20ºC	0.05 day^{-1}
θ_{LPON}	Temperature coefficient for LPON hydrolysis	1.08
k_{RDON}	Mineralization rate for RDON at 20ºC	0.008 day^{-1}
θ_{RDON}	Temperature coefficient for RDON mineralization	1.08
k_{LDON}	Mineralization rate for LDON at 20ºC	0.05 day^{-1}
θ_{LDON}	Temperature coefficient for LDON mineralization	1.08
k_{Nit}	Nitrification rate at 20ºC	0.1 day^{-1}
θ_{Nit}	Temperature coefficient for nitrification	1.08
k_{Nit_DO}	Half saturation constant of oxygen for nitrification	1.0 mgO_2 l^{-1}
k_{Denit}	Denitrification rate at 20ºC	0.05 day^{-1}
θ_{Denit}	Temperature coefficient for denitrification	1.045
k_{Denit_DO}	Half saturation constant of oxygen for denitrification	0.1 mgO_2 l^{-1}

<u>Fraction of respired and grazed phytoplankton into organic pool</u>

f_{RPON}	Fraction of RPON from respiration and grazing	0.15
f_{LPON}	Fraction of LPON from respiration and grazing	0.325
f_{RDON}	Fraction of RDON from respiration and grazing	0.15
f_{LDON}	Fraction of LDON from respiration and grazing	0.175
f_{nh3}	Fraction of ammonia from respiration and grazing	0.2

<u>Exudation of phytoplankton primary productivity into dissolved organic carbon</u>

F_{ExDOC}	Exudation fraction of primary productivity to DOC	0.1

<u>Phytoplankton settling</u>

V_{b1}	Base algal settling rate for winter/spring group at 20ºC	0.5 m day^{-1}
V_{N1}	Nutrient stressed algal settling rate for winter/spring group at 20ºC	1.0 m day^{-1}
V_{b2}	Base algal settling rate for summer group at 20ºC	0.3 m day^{-1}
V_{N2}	Nutrient stressed algal settling rate for summer group at 20ºC	0.7 m day^{-1}
V_{b3}	Base algal settling rate for fall group at 20ºC	0.3 m day^{-1}
V_{N3}	Nutrient stressed algal settling rate for fall group at 20ºC	1.0 m day^{-1}
θ_{sp}	Temperature correction for phytoplankton settling	1.027

<u>Settling of particulate organic nitrogen</u>

V_{PON}	Settling rate for PON at 20ºC	1.0 m day^{-1}
θ_{PON}	Temperature correction for PON settling	1.027

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