Modeling nitrogen and phosphorus cycles and dissolved oxygen in the Pearl River (Zhujiang) Estuary*

I. Model development

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Abstract—In the present study, an ecosystem based water quality model was designed to estimate the biochemical reaction of nutrient and dissolved oxygen in conjunction with a three-dimensional hydrodynamics and sediment model. As both phosphorus and nitrogen successively limit phytoplankton growth in many estuaries, the model simulates both these nutrient cycles using five variables each such as dissolved inorganic nutrient, detritic organic matter, benthic matter, phytoplankton and zooplankton.

Key words 3-D numerical model, nitrogen, phosphorus, dissolved oxygen

1. Introduction

Human activities related to population growth and development of industry and municipality have led to increased loadings of various pollutants into estuaries during the past few decades. These increased pollutant loadings have caused declined estuarine health which can be measured by a variety of indices. In order to obtain solutions to environment problems, resources management agencies are supporting a holistic approach to environmental management. An efficient strategy to prevent or reverse the degradation of important estuarine systems is to make use of numerical models in conjunction with monitoring programs. Through monitoring, not only the present state of the system can be obtained, but it is also possible to evaluate the effectiveness of past and proposed management efforts. Numerical models can be used to study the response of the system to various management options. Numerical models can be applied to study the hydrodynamics, sediment dynamics, water quality dynamics and system ecology in estuarine systems.

Water quality models can be classified into three groups. The first group makes use of a simple regression technique to relate pollutant loading to various estuarine quality indices (e.g., chlorophyll-a concentration, dissolved oxygen concentration and light attenuation). The second group utilizes a box-type water quality model to develop the relationships between pollutant loading and estuarine health indices. The third group uses a process-based multi-dimensional hydrodynamics model in conjunction with a water quality model and an ecological model to determine the response of estuarine health indices to various load reduction strategies.

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Regression-based models often resort to relating estuarine parameters which contain very different temporal and spatial scales (Vollenweider, 1975). Box models usually use both very large spatial grids and time steps, and are often unable to represent important processes which have smaller temporal and spatial scales (Ambrose, 1991; Chapelle et al, 1994). Neither the regression-based models nor the box models contain the detailed cause-effect relationships included in the process-based water quality models. Process-based water quality models generally include component models of the dominant hydrodynamic, chemical, and biological processes (Chen and Sheng, 1995). Details of a process-based water quality model depend on the dominated processes in a particular estuary.

In this study, a three-dimensional (3-D) process-based water quality model is developed as a part of an integrated model, which is used to estimate the biochemical reactions of nutrient and dissolved oxygen in the Pearl River estuary during the flood season. The model results will be presented in Part II of this paper.

2. Modeling strategy

Configured from the Princeton Ocean Model (POM) (Blumberg and Mellor, 1987), a hydrodynamics model for the Pearl River estuary has been developed recently at the Center for Coastal and Atmospheric Research (CCAR) of the Hong Kong University of Science and Technology (HKUST)(Chen, Dong, Wong and et al., 2000). The model domain extends from west of Yamen to east of the Daya bay, from about the 60m isobath to Humen on the northern end. A computational grid was generated utilizing a 261 by 161 matrix of orthogonal horizontal grid cells to cover the model domain (Fig. 1). The generated curvilinear grid has a higher resolution in the Lingdingyang and around Hong Kong (~500 m) and lower resolution in the shelf region (~1 km). In the vertical, 15 layers are set in σ-coordinates with higher resolution near the surface and the bottom to resolve boundary layers. The Pearl River estuary receives fresh water discharged from eight branches that locate at Humen, Jiaomen, Hongqili, Hengmen, Modamen, Jitimen, Hutiaomen and Yamen in turn from northeast to southwest. In the model, the two freshwater branches at Hutiaomen and Yamen have been joined together. All the upstream branches are represented as single-cell-width channels in the model. Since the model is not aimed at processes in the river, the adopted approach is equivalent to have laterally-averaged estuarine models attached to the coastal model.

Fig. 1 Model grid for the Pearl River estuary. Every fourth grid element is shown.

The sediment model was subsequently fully integrated with the hydrodynamics model. The sediment model solves the advection-diffusion equation for cohesive sediment transport using finite difference discretizations on the same horizontal and vertical grid as the hydrodynamics model. Each time-step, the hydrodynamics model supplies the sediment model with grids of current, eddy diffusion coefficients and bed shear stress. The model adopts a new settling velocity formulation which combines the influence of concentration on particle flocculation but also particle break up due to turbulent velocity gradients (Malcherek, et al., 1996). The empirical formulation is necessary and adequate to represent lutoclines that sometimes exist in the water column near the bed. In order to accurately describe the change of the bottom bed, a sediment bed submodel was considered. The dynamics of the sediment bed, including resuspension, deposition, and compaction with time (aging), and the critical shear stress for erosion increases with time after deposition of sediment.

The primary principle for development of water quality model is that the model should not only take into account the key part of biochemical processes, but also simplify the problem to the utmost extent. In the present study, the biochemical processes were considered mainly referring to the work of Chapelle et al (1994) in Vilaine bay of France. A great improvement was made on some processes for the application of the Pearl River estuary. The water quality model is not the box-type model adopted by Chapelle et al (1994), but it is process-based and runs in conjunction with the hydrodynamics model and sediment model, and all models are three-dimensional.

3. Details of the water quality model

Nutrients serve as raw materials for primary production of organic matter in estuaries. Algae and other autotrophs require numerous nutrients, including nitrogen, phosphorus, carbon, silicon, and sulfur, etc. Among theses nutrients, the first three are utilized most heavily by algae. But since carbon is generally abundant in estuaries, Nitrogen and phosphorus are the two major nutrients regulating the ecological balance in estuaries. As both phosphorus and nitrogen successively limit phytoplankton growth during the year, the model simulates both these nutrient cycles using five variables each (Fig. 2 and Table 1). Inorganic nitrogen, phosphorus and phytoplankton, which are directly involved in eutrophication problems, were measures in situ. The zooplankton biomass is not well known. No data are available for detritic and benthic forms. Consequently, these compartments are roughly modeled as non-specific matter pools (N or P). Phytoplankton and zooplankton N/P ratios are constant, and equal the Redfield ratio (16:1). To study the oxygen budget, dissolved oxygen concentrations are also modeled.

In the following, a description of model formulation is first presented, followed by an expatiation of biochemical reactions and settling processes occurring in the water column. A brief explanation about numerical methods is then given.

Fig. 2 Biochemical processes considered in the water quality model. Solid lines indicate nutrient fluxes, while dashed lines express oxygen fluxes.

Table 1. Definition of the variables of the model

Symbol	Definition	Unit
NMIN	Inorganic nitrogen	μmol N L^{-1}
NPHY	Phytoplanktonic nitrogen	μmol N L^{-1}
NZOO	Zooplanktonic nitrogen	μmol N L^{-1}
NDET	Detritic nitrogen	μmol N L^{-1}
NBEN	Benthic nitrogen	mmol N m^{-2}
PMIN	Inorganic phosphorus	μmol P L^{-1}
PPHY	Phytoplanktonic phosphorus	μmol P L^{-1}
PZOO	Zooplanktonic phosphorus	μmol P L^{-1}
PDET	Detritic phosphorus	μmol P L^{-1}
PBEN	Benthic phosphorus	mmol P m^{-2}
DO	Dissolved oxygen	mg L^{-1}

3.1 Model formulation

Except for benthic nutrients (NBEN and PBEN), the transport of each predicted substance is separated into two kind of processes: the advection-diffusion processes (hydrodynamics) which is common to all matters, and the internal processes that consists mainly of biochemical reactions and particle settling processes. These processes may be expressed as follows:

a) Advection-diffusion processes

$$\frac{\partial Ci}{\partial t} = -\frac{\partial uCi}{\partial x} - \frac{\partial vCi}{\partial y} - \frac{\partial wCi}{\partial z} + \frac{\partial}{\partial x}\left(K_h \frac{\partial Ci}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_h \frac{\partial Ci}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_v \frac{\partial Ci}{\partial z}\right)$$

Where Ci is concentration of matter I; *t* is time; *u, v, and w* are velocities in x, y and z coordinate directions, respectively; while K_h and K_v are vertical and horizontal eddy diffusion coefficients, respectively. The values for *u,v, w,* K_h and K_v are provided by the hydrodynamics model.

b) Internal processes and settling processes of particulate matters

$$\frac{\partial NMIN}{\partial t} = -Pgrow \cdot NPHY + Nremin \cdot NDET + Zexcr \cdot NZOO$$

$$\frac{\partial NPHY}{\partial t} = (Pgrow - Pexu - Pmort - PHYsedim) \cdot NPHY + \frac{\partial (w_{phy}.NPHY)}{\partial z} - Zgraze \cdot NZOO$$

$$\frac{\partial NZOO}{\partial t} = (Zgaze - Zexcr - Zegest - Zmort) \cdot NZOO$$

$$\frac{\partial NDET}{\partial t} = (Pexu + Pmort) \cdot NPHY + (Zegest + Zmort) \cdot NZOO + Nresusp.NBEN / h_B - DETsedim + Nremin) \cdot NDET + \frac{\partial (w_{om}.NDET)}{\partial z}$$

$$\frac{\partial PMIN}{\partial t} = -Pgrow \cdot PPHY + Premin \cdot PDET + Zexcr \cdot PZOO$$

$$\frac{\partial PPHY}{\partial t} = \frac{\partial NPHY}{\partial t} \cdot \frac{1}{r_{N/P}}$$

$$\frac{\partial PZOO}{\partial t} = \frac{\partial NZOO}{\partial t} \cdot \frac{1}{r_{N/P}}$$

$$\frac{\partial PDET}{\partial t} = (Pexu + Pmort) \cdot PPHY + (Zegest + Zmort) \cdot PZOO + Presusp.PBEN / h_B - (DETsedim + Premin) \cdot PDET + \frac{\partial (w_{om}.PDET)}{\partial z}$$

$$\frac{\partial DO}{\partial t} = Ophotos - Oremin - Obenthos - Orespphy - Orespzoo + Oair$$

Where h_B is the thickness of the bottom layer of the model in meters. Internal processes involved in the model are briefly described below and the mathematical formulae are summarized in Table 2. The parameters used in the water quality model for the Pearl River estuary are defined in Table 3.

Benthic nutrients only act as pools for total sediment nitrogen and phosphorus. No mineralization occurs in the sediment, but exchanges between benthic pools and suspended detritic pools take place through sedimentation and resuspension. The corresponding expressions are

$$\frac{dNBEN}{dt} = DETsedim \cdot NDET \cdot h_B + PHYsedim \cdot NPHY \cdot h_B - Nresusp \cdot NBEN$$

$$\frac{dPBEN}{dt} = DETsedim \cdot PDET \cdot h_B + PHYsedim \cdot PPHY \cdot h_B - Presusp \cdot PBEN$$

Table 2. Internal processes used in the model

Function	Definition	Formula
Pgrow	Phytoplankton growth rate	$\mu_{\max} \cdot f_I(I) \cdot f_T(T) \cdot f_N(N)$
$f_T(T)$	Temperature effect	$e^{k_T \cdot (T-20)}$
$f_I(I)$	Light effect on phytoplankton	$\frac{I}{I_{opt}} \cdot e^{1-\frac{I}{I_{opt}}}$
I(z,t)	Light at the depth z and time t	$I_{surf}(t) \cdot e^{-\int_z^0 k_e \cdot dz}$
k_e	Light extinction coefficient	$k_e^{'} + 0.0088 \cdot (r_{chlo/N} \cdot NPHY) + 0.054 \cdot (r_{chlo/N} \cdot NPHY)^{2/3}$
$k_e^{'}$	Non-chlorophyllic extinction light	$k_{ew} + 0.052 \cdot SSC + 0.174 \cdot (r_{detN/N} \cdot NDET + r_{detP/P} \cdot PDET)$
$f_N(N)$	Nutrient limitation of phytoplankton	$\min\left(\frac{NMIN}{NMIN + k_N}, \frac{PMIN}{PMIN + k_P}\right)$
Pmort	Phytoplankton mortality rate	$mphy \cdot f_T(T)$
Pexu	Phytoplankton exudates rate	$(1 - assphy) \cdot Pgrow$
PHYsedim	Phytoplankton sedimentation rate related to the bed shear stress (τ)	$\begin{cases} W_{phy} \cdot (1.0 - \tau/\tau_D)/h_B & \tau < \tau_D \\ 0 & \tau \geq \tau_D \end{cases}$
Zgraze	Zooplankton grazing rate	$r_{\max} \cdot f_T(T) \cdot (1 - e^{-k_z \cdot \max(0, NPHY - P_0)})$
Zegest	Zooplankton egestion rate	$(1 - asszoo) \cdot Zgraze$
Zexcr	Zooplankton excretion rate	$excrzoo \cdot f_T(T)$
Zmort	Zooplankton mortality rate	$mzoo \cdot f_T(T)$
$f_{DO}(DO)$	Oxygen effect on biochemical reactions	$\frac{DO}{DO + k_{DO}}$
Nremin	Organic nitrogen mineralization	$minnit \cdot f_T(T) \cdot f_{DO}(DO)$
DETsedim	Organic matter sedimentation rate related to the bed shear stress (τ)	$\begin{cases} W_{om} \cdot (1.0 - \tau/\tau_D)/h_B & \tau < \tau_D \\ 0 & \tau \geq \tau_D \end{cases}$
Nresusp	Benthic nitrogen resuspension related to the bed shear stress (τ)	$\begin{cases} resusN \cdot (\tau/\tau_E - 1.0) & \tau > \tau_E \\ 0 & \tau \leq \tau_E \end{cases}$
Presusp	Benthic phosphorus resuspension related to the bed shear stress (τ)	$\begin{cases} resusP \cdot f_T(T) \cdot (\tau/\tau_E - 1.0) & \tau > \tau_E \\ 0 & \tau \leq \tau_E \end{cases}$
Premin	Organic phosphorus mineralization	$minphos \cdot f_T(T) \cdot f_{DO}(DO)$
Ophotos	Oxygen production by photosynthesis	$rps \cdot Pgrow \cdot NPHY \cdot qps$
Oremin	Oxygen consumption by mineralization	$rmin \cdot Nremin \cdot NDET$
Obenthos	Oxygen consumption by benthic demand	$oben \cdot f_B(NBEN) \cdot f_T(T) \cdot f_{DO}(DO)/h_B$
Orespphy	Phytoplankton respiration	$(respb + respst) \cdot rps \cdot NPHY$
respst	Stress respiration rate	$(1 - f_I(I)) \cdot respstmax$
Orespzoo	Zooplankton respiration	$respzoo \cdot NZOO$
Oair	Aeration	$k_a \cdot (DO_{sat} - DO)$

Table 3. Parameters used in the water quality model and the corresponding values for the Pearl River estuary

Parameter	Definition	Value
Phytoplankton		
μ_{max}	Maximal phytoplankton growth rate @ 20°C	4.0 day^{-1}
k_N	Half saturation constant for N-limitation	1.5 μmol N L^{-1}
k_P	Half saturation constant for P-limitation	0.05 μmol P L^{-1}
I_{opt}	Optimal light intensity	70 wm^{-2}
k_{ew}	Light extinction due to particle-free water and color	0.3 m^{-1}
k_T	Temperature coefficient	0.063 $°C^{-1}$
mphy	Phytoplankton mortality rate @ 20°C	0.005 day^{-1}
assphy	% Phytoplankton assimilation	0.8
w_{phy}	Phytoplankton sinking speed	0.2 m day^{-1}
Zooplankton		
r_{max}	Maximal zooplankton growth rate @ 20°C	1.056 day^{-1}
k_z	Ivlev constant	0.05 L μmol N^{-1}
P_0	Ivlev grazing threshold	0.1 μmol N L^{-1}
asszoo	% Zooplankton assimilation	0.6
excrzoo	Zooplankton excretion rate @ 20°C	0.025 day^{-1}
mzoo	Zooplankton mortality rate @ 20°C	0.025 day^{-1}
Nitrogen		
minnit	Nitrogen mineralization rate @ 20°C	0.2 day^{-1}
w_{om}	Organic matter sinking speed	0.5 m day^{-1}
resusN	Nitrogen resuspension rate	0.01 day^{-1}
k_{DO}	Half saturation constant for O_2-limitation	1 mg L^{-1}
Phosphorus		
minphos	Phosphorus mineralization rate @ 20°C	0.9 day^{-1}
resusP	Phosphorus resuspension rate	0.02 day^{-1}
Oxygen		
Rps	O_2 (mg) produced/N (μmol) photosynthetized	0.212 mg O_2 μmol N^{-1}
Rmin	O_2 (mg) consumed/N (μmol) mineralized	0.29 mg O_2 μmol N^{-1}
Qps	Photosynthetic ratio	2
Oben	Oxygen consumption by benthic demand	1 g O_2 m^{-2} day^{-1}
Respb	Phytoplankton basal respiration rate	0.01 day^{-1}
respstmax	Maximal phytoplankton stress respiration rate	0.1 day^{-1}
respzoo	Zooplankton respiration rate	0.084 mg O_2 day^{-1}μmol N^{-1}
Other		
$r_{N/P}$	N/P ratio in phytoplankton and zooplankton	16 mol/mol
$r_{chlo/N}$	Chlorophyll-a / N ratio	1.0 μg Chl a / μmol N
$r_{detN/N}$	Nitrogenous detritus / N ratio	0.2 mg / μmol N
$r_{detP/P}$	Phosphoric detritus / P ratio	3.5 mg / μmol P
τ_D	Critical shear stress for deposition	4 dynes cm^{-2}
τ_E	Critical shear stress for erosion	0.25 dynes cm^{-2}

3.2 Processes description

The phytoplankton growth rate is a multiplicative function of respective effects of temperature, nutrients and available light. The temperature effect is exponential (Eppley, 1972), the inhibitory effect of high temperature values being neglected. This relationship is typically used when phytoplankton are simulated as a single state variable. It usually implies that there will always be species that grow at any particular temperature. Further it can also be used when the simulations are performed for temperatures lower than the optimal temperature for a particular species. Steele's (1962) function is used to describe light control of photosynthesis. It represents a light dependence that is zero when light intensity is zero at night, increases to a peak growth rate at an optimal light intensity, and then decreases at higher light intensity. In order to obtain the available light intensity at every computational grid points, a serial calculation must be done. The strength of solar radiation penetrating the sea surface is influenced by ellipticity of the earth orbit, absorbtion of atmospheric clouds and effect of solar altitude. On the other hand, the solar radiation that reaches the sea surface includes the ultraviolet range (290 - 380 nm), the visible range (380 - 760 nm), and the infra-red (760 - 3000 nm). As to primary production in estuarine systems, ecologists are normally concerned with light in the range of wavelengths from 400 – 700 nm. Defined as “Photosynthetically Active Radiation” (PAR), this range of irradiance provides the predominant source of energy for autotrophic organisms. The formula (Moisan, 1993) of the available light intensity at sea surface is

$$\begin{cases} I_{surf} = PAR_{ell} \cdot cznt(1-0.6072+1.1871cznt)\,[1-cloud(0.7726 \\ \qquad -0.2782\sqrt{1-cznt^2})], & if\ cznt>0 \\ I_{surf}=0, & if\ cznt \le 0 \end{cases},$$

with $PAR_{max} = solar \cdot trans \cdot PARf\,(1-albedo)$,

$PAR_{ell} = PAR_{max}(1+0.033cday)$,

$$cznt = chour \cdot \cos(-0.406cday) \cdot \cos(\pi \cdot lat/180) + \sin(-0.406cday) \cdot \sin(\pi \cdot lat/180),$$

$cday = \cos(\pi \cdot day/180)$,

$chour = \cos[15\pi(hour-12)/180]$,

where the maximum strength of solar radiation, *solar*=1353 w/m^2, the fraction of total radiation transmitted through atmosphere, *trans*=0.8, the albedo of the sea surface, *albedo*=0.04, The PAR fraction of the total solar radiation, *PARf*=0.43. Taking ellipticity of the earth orbit into account, the maximum value of PAR, PARmax, then becomes *PARell*, and *Isurf* is the ultimate available light intensity for Photosynthesis at the ocean surface. *day* is the date in Julian days, hour is the time between 0 and 24. *lat* is the latitude in degrees, and *cloud* is the local cloud amount in percent。Light intensity decreases with the depth according to an exponential equation, depending on the light extinction coefficient. The latter is split into a chlorophllic part describing self shading (Riley, 1956) and into a non-chlorophyllic part related to sea state, suspended sediment concentration (SSC, unit: mg/L) and detritus concentration (Di Toro, 1978). Nutrient limitation follows the Liebig’s law of the minimum: only the most limiting nutrient controls phytoplankton growth and also follows Michaelis-Menten equation which is linearly proportional to concentration at low nutrient levels and approaches a constant value of one at high levels.

Grazing follows the Ivlev function (Ivlev, 1955). Assimilation is a constant fraction of the ingested food, with the non-assimilated fraction rejected as faeces (Butler et al., 1969). Similarly, for phytoplankton, a part of photosynthetized matter is lost as exudates (Mague et al., 1980). Phytoplankton and zooplankton mortality and zooplankton excretion are function of temperature same as the phytoplankton growth rate. Mineralization of organic matter is described by a simple temperature- and oxygen-dependent formula, without detailing the different chemical steps.

Particulate matters always sinking in the water column. The sinking velocity is constant, higher for detritic matter than for living phytoplankton (Smayda and Bienfang, 1983). The sedimentation and resuspension merely occur at the bottom. These two processes follow the formulae for cohesive sediment (Guan, Wolanski and Dong, 1998). As far as phosphorus is concerned, the flux at the sediment-water interface is largely dependent on the absorption-desorption reactions in the sediment, which are related to temperature, oxygen and pH. As a first approximation, phosphorus flux at the interface is expressed as a function of the temperature (Kamp-Nielsen, 1975).

Production of oxygen by photosynthesis, consumption by respiration and mineralization are inferred from the stoichiometric O_2/N ratios. Special attention is paid to phytoplankton respiration, which is divided into basal and stress components (Raven and Beardall, 1981). An empirical relationship between the stress rate and light limitation is proposed to emphasize the increase in respiration when light is reduced. The aeration takes place only at the surface layer and the benthic demand only at the bottom. The benthic compartment is considered as a function of benthic matters and temperature. The mean value of benthic oxygen demand is obtained from in situ measurements. Diffusion of the oxygen at sea surface depends on the reaeration coefficient and on the difference between oxygen concentration and its saturation value. The reaeration rate, *ka* is calculated in the model using the formula proposed by Thomann and Fitzpatrick (1982) for the Potomac estuary. This method calculates reaeration as function of velocity, depth, and wind speed as:

$$k_a = 3.93\frac{\sqrt{U_0}}{H^{3/2}} + \frac{0.728U_w^{0.5} - 0.317U_w + 0.0372U_w^2}{H}$$

where U_0 is the velocity of the surface layer, in m/s; H is the depth of the surface layer, in meters; and Uw is wind speed, in m/s. Dissolved oxygen saturation, DO_{sat}, is determined as a function of absolute temperature Ta and salinity S (APHA, 1992)

$$\begin{aligned}\ln DO_{sat} &= -139.34411 + (1.575701\times10^5)\cdot T_a^{-1} - (6.642308\times10^7)\cdot T_a^{-2}\\ &+ (1.243800\times10^{10})\cdot T_a^{-3} - (8.621949\times10^{11})\cdot T_a^{-4}\\ &- S\cdot(1.7674\times10^{-2} - 1.0754\times10^1\cdot T_a^{-1} + 2.1407\times10^3\cdot T_a^{-2})\end{aligned}$$

where $T_a = T + 273.15$, temperature , T, is in °C.

3.3 Numerical methods

Because phytoplankton and zooplankton exist as individuals, once the nitrogen contents of phytoplankton and zooplankton are computed, the phosphors contents will be known through nitrogen contents being divided by the Redfield constant. However, there are still 7 equations related to water quality elements, their solutions increase significantly the computation cost of the whole model. The more variables are taken into account in the water quality model, the larger the computation cost becomes. Therefore, the consideration on the computation cost usually makes us simplify biochemical processes contained in the model to the acceptable extent of the specified application.

In the simulating process, the water quality model runs in conjunction with the 3-D hydrodynamics and sediment models (Fig. 3), i.e., all models adopt the same grids and time steps. The solution for water quality is separated into two parts with one for dynamic processes including advection-diffusion processes and settling processes and another for biochemical processes. These two parts of solution are obtained in turn. In the integrated model, the numerical methods solving the conservation equations of water quality are same as those solving other scalar equations, except that the settling velocities should be considered in the vertical discretization of the equations of organic detritus and phytoplankton. The hydrodynamics model provides vertical and horizontal eddy diffusion coefficients for the sediment and water quality models, and the sediment model supplies the sediment concentration for the water quality model. In order to get the biochemical part of solution, quantitative changes among all water quality variables need to be implemented according to relationships mentioned above.

Fig.3 Block diagram of the integrated model system

4 Conclusions

In the present study, an integrated model has been introduced and the water quality model was in detail described as an important part. In the water quality model, nutrient cycles contain five components, and every component includes two categories: nitrogen and phosphorus. Further, dissolved oxygen concentrations are also simulated in the model. The method simulating water quality adopt 3-D model instead of the traditional box-type model. In the simulating process, the water quality model runs in conjunction with the hydrodynamics and sediment models, i.e., all models own same resolutions both in space and in time. The 3-D model is very different from the box-type model, especially in treatments of some processes such as particle sinking, sedimentation and resuspension at the sediment-water interface, and so on. The integrated model system is driven by specified boundary conditions, and the model results will be shown in Part II of this paper.

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