International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

A Review of Water Quality Models

Nibedita Pattnayak

Orissa Engineering College, Department of Chemistry, BBSR, India

Abstract: ***Water quality models are important in predict- ing the changes in surface water quality for environmental management. A range of water quality models are wildly used, but every model has its advantages and limitations for specific situations. The aim of this review is to provide a guide to researcher for selecting a suitable water quality model. Eight well known water quality models were selected for this review: SWAT, WASP, QUALs, MIKE 11, HSPF, CE-QUAL-W2, and EFDC. Maintaining water quality and predicting the fate of water pollutants are one of the important tasks of present environmental problems. The best tool for predicting different pollution scenarios are the simulation of mathematical models which can provide a basis and technical support for environmental management. Today, there is a growing interest in network water quality modelling. The water quality issues of interest relate to both dissolved and particulate substances. For dissolved substances the main interest is in residual chlorine and (microbiological) contaminant propagation; for particulate substances it is in sediment leading to discolouration. There is a strong influence of flows and velocities on transport, mixing, production and decay of these substances in the network. This imposes a different approach to demand modeling which is reviewed in this article.***

Keywords: Water Quality Model; Environmental Management; Water Pollutants, water quality models : SWAT, WASP, QUALs, MIKE 11, HSPF, CE-QUAL-W2, and EFDC

1. Introduction

Now-a-days a rapid growth of industrialization, urbanization and agricultural practices results in the pollution of water bodies with high rate. These practices not only pollute the reservoirs with high pollutant concentration but also increase number of pollutants. The discharging of degradable wastewater in water bodies result in decrease in water quality generally and particularly DO (Dissolved Oxygen) concentrations [1]. Water quality models are commonly applied for management, planning and pollution control. Each of these requires a different level of confidence in the model output. With the influence of human economic activity, environmental degradation and activity zones (e.g., house- hold water supply, agriculture, hydropower and fisheries), the water quality is threatened by point (PS) and non-point (NPS) source pollution. Thus, hydrologic/water quality sources and application potential. Those papers provide detailed information about the models and their capability. However, the description of the models was of limited scope (e.g., just DO). Therefore, in this review, we describe not only the capability of the models but also their application to particular situation.In this paper, eight water quality models that are used wildly around the world are described including intended use, development, simulation elements, basic principle, limitations, model strengths and their application to particular situations. The models, SWAT, WASP, QUALs (QUAL2E, QUAL2K, QUAL2Kw), MIKE 11, HSPF, CE-QUAL-W2, and EFDC are included. This review provides support for researchers to make informed decisions when choosing an appropriate model for their work.[2].

To understand the present pollutant load, pollutant transfer and future cause – effect relation between pollutant source and water quality, Mathematical Modelling is considered as one of the best tools for estimation. With the help of these models the response of the aquatic environment to different scenarios can also be predicted. Mathematical modelling can also be beneficial for all those sites which are inaccessible due to special environmental issues. Therefore, water quality models become an important tool to identify water environmental pollution and the final fate and behaviours of pollutants in water environment [3]. With the development of model theory and the fast-updating computer technique [4], more and more water quality models have been developed with various model algorithms [5,6]. Up to date, tens of types of water quality models including hundreds of model software have been developed for different topography, water bodies, and pollutants at different space and time scales [6,7].

2. Classification of WQMs

Models have been developed for various pollutants, the nature of source (point or diffuse), and for different river characteristics like morphological, hydraulic and ecological. They estimate changes in contaminant concentrations in a given river stretch integrating the assimilative capacity available from physical, chemical and biological reactions occur- ring within the system[8]. Depending on the objectives, WQMs can be broadly classified as simulation models (to predict water quality changes due to a pollution source) and opti- mization models (for optimal allocation of resources)[9,1011]. Figure 1 illustrates various types of WQMs.

Optimization models can be further divided into linear programming model [9],non-linear programming model (12) and dynamic programming model (12). A physical simulation model is built to produce a scaled result which can relate back to the real system whereas a mathematical model is based on a set of equations solved numerically to predict the water quality (13).

Mathematical models can be further classified on the basis of process description as statistical/empiri- cal or mechanistic; data type as deterministic or stochastic; solution types as numerical or analytical; and level of presentation as lumped or distributed.

Water Quality Models

The models selected for application here are mostly mechanistic models. Water quality models are developed to predict contaminant fate and transport in water-bodies such as rivers, reservoirs, lakes and estuaries. They can be helpful tools for water resource management. All these models can be useful in management and improvement of water quality.

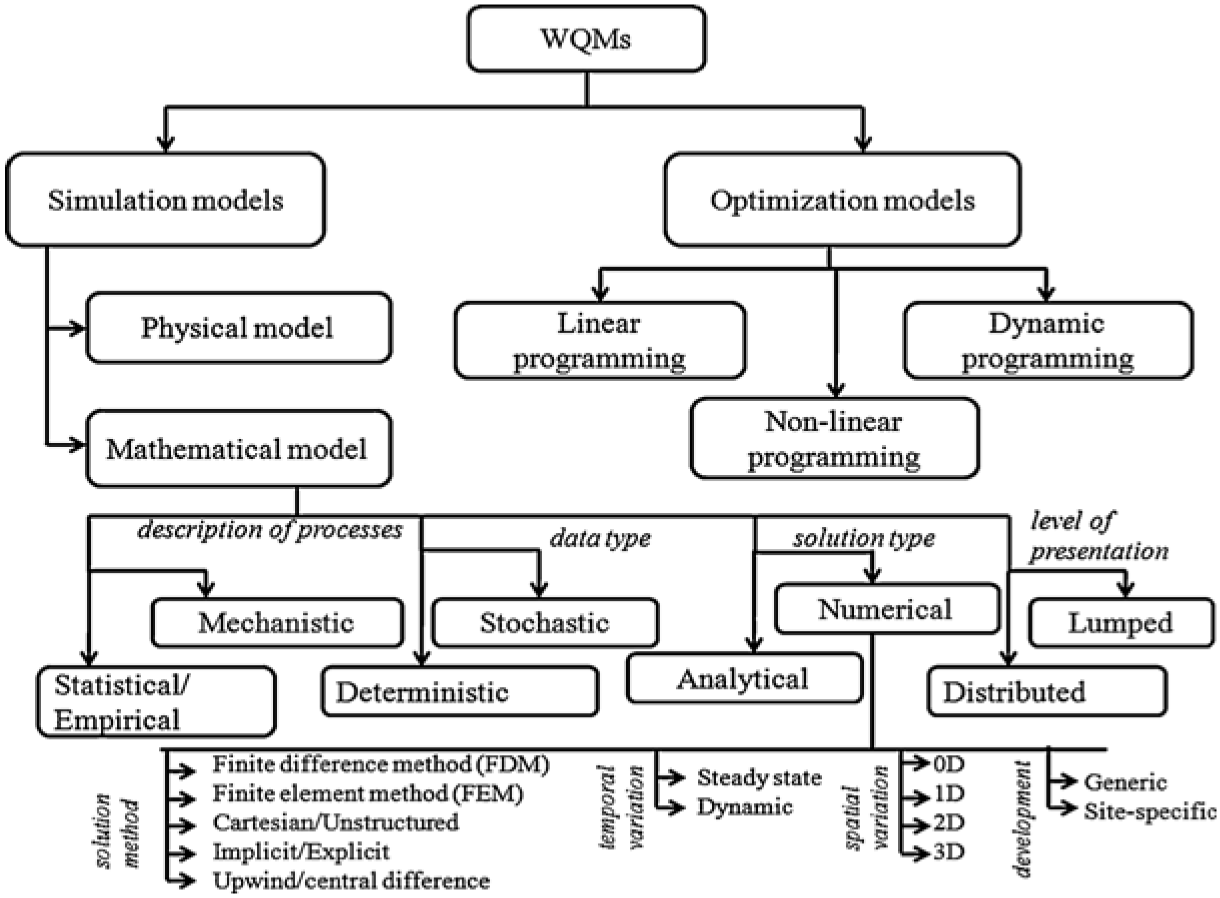

Figure 1: Types of Water Quality Models

SWAT

SWAT (Soil Water and Analysis Tools), a physical-based model, was developed by the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) in the early 1990s for the prediction of the long-term impact of rural and agricultural management practices (such as detailed agricultural and planting, tillage, irrigation, fertilisation, grazing and harvesting procedures) on water, sediment and agricultural chemical yields in large, complex watersheds with varying soils, land use and management conditions [17]. The model is available without cost from http://www.brc.tamus.edu/swat. Several versions (S WAT9 8.1, S WAT 99.2, SWAT2000, SWAT2005, SWAT2009 and WAT2012) are currently available. The model can perform daily simulation of groundwater flow, and nutrient and water transportation from channels and reservoirs and, in particular, the calculation of the parameters (algae, DO and carbonaceous BOD) that impact the quality of stream water.

There has been a range of applications of this model in different contexts. Abbaspour and Schuol [14] addressed some calibration and uncertainty issues using SWAT to model a 4 million km^2 area in West Africa. They found SWAT could be used for large-scale water quantity investigations and a 95% prediction uncertainty band was necessary to bracket 80% of the observed data, indicating that the uncertainty of the conceptual model was quite large. They indicated that some processes (for instance large reservoirs regulating the runoff) in Niger might be important, however in the large Inner Niger Delta, delaying the runoff and evaporation losses were not included in the model. For the land phase nutrient cycle, SWAT was used to simulate the organic and mineral nitrogen and phosphorus fractions by separating each nutrient into component pools. Then, N and P could increase or decrease depending on their transformation and/or additions/losses occurring within each pool [14,15]. In addition, in NPS water quality for nutrients and sediments, Chen et al. [16] used the SWAT model.

WASP

WASP (Water Quality Analysis Simulation Program) is a surface water quality model developed by the US Environmental Protection Agency (EPA) for the water quality modeling [17,18]. WASP is a 1, 2 and 3 dimensional dynamic model. Currently it has seven versions (WASP1–7).It can be downloaded at no cost from http://www.epa.gov/athens/wwqtsc/html/wasp.html. In WASP, different interacting systems are developed comprising ammonia, nitrate, phosphate, phytoplankton, biochemical oxygen demand (BOD), DO, organic nitrogen and organic phosphorus [27, 28]. It can be used to analyze a variety of water quality problems in such diverse water bodies as ponds, streams, lakes, reservoirs, rivers, estuaries and coastal waters. WASP can also be linked with hydrodynamic and sediment transport models that provide flows, depths, velocities, temperature, salinity and sedi- ment fluxes. The latest version, WASP7, comes with two general kinetic modules: TOXI for toxicants and EUTRO for conventional water quality to solve conventional pollution (involving DO, BOD, nutrients, and eutrophica- tion) and toxic pollution (involving organic chemicals, metals and sediment).

MIKE 11

MIKE 11 is a powerful and popular hydrological modeling system, a one-dimensional modeling tool for the detailed design, management, and operation of both simple and complex river and channel systems, developed by the Danish Hydraulic Institute (DHI) (http://www.mikebydhi. com). It is composed of several modules, including rainfall runoff (RR), hydrodynamic (HD) and advection dispersion (AD), which can be used in combination or as stand-alone simulators [19]. MIKE 11-NAM is a rainfall runoff model that is part of the MIKE 11 RR module. MIKE 11 has been wildly used by researchers mainly for rivers and lakes. Christian and Refsgaard [20] used the MIKE 11-NAM coupled with MIKE SHE and WATBAL on three catchments in Zimbabwe for water resource decision making, and it worked well using at least one year's data for calibration. Thompson et al. [21] used a coupled MIKE SHE/MIKE 11-HD model for a lowland wet grassland in South-east England. The results showed that the system could make an accurate representation of the macropore flow associated with soil cracking and swelling, and the seasonal dynamics of groundwater and ditch water and were generally consistent with the observed data. In addition, Liu et al. [22] coupled a spatially distributed hydrological model for catchment hydrology and groundwater, implemented in the MIKE-SHE hydrological modeling software of DHI Water and Environment, with a MIKE 11 hydraulic model to simulate dynamic changes in groundwater within the study area for both flood and dry seasons. The results indicated that the proposed methodology is applicable for the management of water resources in arid regions. The modeling and hybrid fractal–wavelet method study allowed quantifica- tion of the processes affecting groundwater levels and provided an insight into their implications in exploring groundwater level management.

QUALs

The US Environmental Protection Agency (EPA) released a series of QUAL models such as QUAL2E, QUAL2E-UNCAS, QUAL2K and QUAL2Kw. The models allow the simulation of up to 15 parameters (DO, BOD, temperature, algae as chlorophyll a, organic nitrogen as N, ammonia as N, nitrite as N, nitrate as N, organic phosphorus as P, dissolved phosphorus as P, coliform bacteria, one arbitrary non-conservative constituent solute and three conservative constituent solutes) associated with water quality in any combination chosen by the user. For one-dimensional, steady-state models, these elements, hydrological balance, heat balance and material balance are influenced by flow, temperature and concentration. QUAL2E is the latest version of QUAL-II and Soon and Park [23] used it to prove that autochthonous sources and denitrification played an important role in BOD and nitrogen dynamics. QUAL2E has been wildly used in water quality prediction and pollution management. Palmieri et al. [24] predicted the water quality of the Corunbatai River, located in São Paulo State, Brazil using QUAL2E, and the results showed that the sensitivity analyses were more sensitive to the BOD decay coefficient. Ritu Paliwal et al. used QUAL2E to determine the pollution loads in the Yamuna River. Four different pollution scenarios were used to examine the influence on river water quality. The results showed that it was suitable for water quality if the flow rate was more than 10 m^3\$s^{-1}. In addition, the uncertainty analysis provided a useful method for prediction of model parameters, DO and BOD. Bailey et al. [25] used a coupled QUAL2E-OTIS model to investigate the factors that govern DO and NO_3 in space and time for the Lower Arkansas River Basin in south-eastern Colorado. The results showed that many processes (including algal growth and respiration, and chemical kinetic reactions) had a time-dependant influence due to seasonal changes in water temperature and solar radiation. Other processes (groundwater discharge and solute mass loading) were of moderate influence in the Arkansas River, but of very strong influence in its tributaries. Thus efficient remediation strategies may be taken in time. Also, Salvetti et al. [26] used two different models: QUAL2E (the simulation of the dry weather scenario) and BASINS-SWAT (the simulation of the wet weather scenario) to analyze the source apportionment of a river basin, the Dese-Zero river, located within the North-Eastern part of the Venice Lagoon Watershed (VLW), Italy. The results showed that about 30% surface runoff loads, about 15% point sources and about 55% of the total annual load were related to non-rain-driven diffuse sources.

HSPF

HSPF (Hydrological Simulation Program-FORTRAN) was also developed by US Environmental Protection Agency (USEPA) to represent contributions of sediment, nutrients, pesticides, conservatives and fecal coliforms from agricultural areas, and to continuously simulate water quantity and quality processes on pervious and impervious land surfaces and in streams and well-mixed impound- ments [27]. HSPF is based on the original Stanford Watershed Model IV [28] and combines three previously developed models: Agricultural Runoff Management Model, Non-point Source Runoff Model, and Hydrological Simulation Program (HSP) including HSP Quality. Details are available at http://www.epa.gov/ceampubl/swater/hspf/ index.htm. It can simulate the water quality elements including temperature, fecal coliforms, DO, BOD, total suspended solids, nitrates, orthophosphates, and pH. Kim and Chung [29] developed an index-based robust decision making framework for watershed management dealing with water quantity and quality issues in a changing climate using HSPF to understand the watershed compo- nents and processes, producing an improved system for integrated water management (IWM). Fonseca et al. [30] used HSPF to predict the impact of PS and NPS pollution on the water quality of the Lena River. The model simulated detailed watershed temperatures and concentra- tions of various water constituents in the river.

CE-QUAL-W2

CE-QUAL-W2 model (W2), is a waterp quality and hydrodynamic model with two dimensions (longitudinal and vertical) for rivers, estuaries, lakes, reservoirs and river basin systems. It was developed by the US Army Corps of

Engineers' Waterways Experiment Station[31]. It is available at no cost from www.ce.pdx.edu/w2. The model assumes lateral homogeneity, which is particularly suited for water systems with little lateral variations in the water quality constituents. The model can simulate DO, TOC, BOD, *Escherichia coli* and algae.

EFDC

EFDC (Environmental Fluid Dynamics Code), developed by Hamrick [32], is a versatile surface water modeling system, which includes hydrodynamics, sediment trans- port, toxic contaminant transport and water quality- eutrophication components. EFDC has become one of the most widely used hydrodynamic models. EFDC has been applied to different water bodies including rivers, lakes, reservoirs, wetlands, estuaries, and coastal regions in environmental assessment and management [33–35]. Franceschini and Tsai [36] coupled two numerical models, the Environmental Fluid Dynamic Code (EFDC), for the hydrodynamic portion, and WASP, for the fate and transport of contaminants, using the data from May 1995 to March 1997 on Lake Eris, and achieved an improved comparison of model predictions and measured data. For algae growth prediction, Wu and Xu [37] used the EFDC model to describe and simulate the eutrophication process in the Daoxiang Lake, Beijing. The results showed that EFDC was effective at predicting the algal blooms through chlorophyll-a. To examine salinity spread, Xu et al. [38] used the model to calibrate and verify against water level variation, temperature and salinity variations during 2003 and 2001 in the Pamlico River Estuary.

3. Conclusion

In the changing environmental scenario the water quality models are playing very important role in predicting the present and future status of water pollution. Many water quality models have been developed since 1925 and some developed countries have provided some regulated models for surface water quality simulation. water quality models are important for man- agement, planning and pollution control for government, so eight models are described in this review. Each model is described from its intended use, development, simulation elements, basic principle and applications. There are one- dimensional models for rivers (e.g., SWAT, MIKE 11 and QUAL-2E), two-dimensional models for lakes and reservoirs (e.g., CE-QUAL-W2), and three-dimensional models for estuaries (e.g., WASP and ELCOM-CAE- DYM). With the increasing importance of water quality, more and more elements are included in models to assist in studying and managing water quality, and there are some challenges: the models need a substantial amounts of data that should be valid, there could be large deviation between the facts and the simulation depending on the assumptions because models do not include mechanisms of pollutants and are not clear about the migration of contaminants, and we cannot determine the accuracy of the selected parameter, so the result will be inaccurate. Hence the standardization of some water quality models are becoming necessary for most developing countries for the study of efficient environmental impact assessment.

References

[1] Nakhaei, N. and Shahidi, A.E. (2010) Waste Water Discharge Impact Modeling with QUAL2K, Case Study: The Za- yandeh-Rood River. International Environmental Modelling and Software Society (IEMSS), Ottawa. [Citation Time(s):1]

[2] Liangliang GAO[1], Daoliang LI (✉)[2] (2014) A review of hydrological/water-quality models 1(4): 267–276

[3] Q. G. Wang, W. N. Dai, X. H. Zhao, F. Ding, S. B. Li, and Y. Zhao, "Numerical model of thermal discharge from Laibin power plant based on Mike 21," Research of Environmental Sciences, vol. 22, no. 3, pp. 332–336, 2009 (Russian). View at Google Scholar

[4] S.-M. Liou, S.-L. Lo, and C.-Y. Hu, "Application of two-stage fuzzy set theory to river quality evaluation in Taiwan," Water Research, vol. 37, no. 6, pp. 1406–1416, 2003. View at Publisher · View at Google Scholar. View at Scopus

[5] Q. G. Wang, W. N. Dai, X. H. Zhao, F. Ding, S. B. Li, and Y. Zhao, "Numerical model of thermal discharge from Laibin power plant based on Mike 21," Research of Environmental Sciences, vol. 22, no. 3, pp. 332–336, 2009 (Russian). View at Google Scholar

[6] J. H. Bai, H. F. Gao, R. Xiao, J. J. Wang, and C. Huang, "A review of soil nitrogen mineralization in coastal wetlands: issues and methods," CLEAN—Soil, Air, Water, vol. 40, no. 10, pp. 1099– 1105, 2012. View at Publisher · View at Google Scholar

[7] X. J. Cao and H. Zhang, "Commentary on study of surface water quality model," JournaI of Water Resources and ArchitecturaI Engineering, vol. 4, no. 4, pp. 18–21, 2006 (Russian). View at Google Scholar

[8] Cox BA (2003a) A review of dissolved oxygen modelling techniques for lowland rivers. Sci Total Environ 314–316:303–334

[9] Bowen RL, Young RA (1985) Financial and economic irrigation net benefit functions for Egypt's northern delta. Water Resour Res 21(9):1329–1335

[10] Dudley NJ (1988) A single decision-maker approach to irriga- tion reservoir and farm management decision making.Water Resour Res 24(5):633–640

[11] Zoppou C (2001) Review of urban storm water models. Environ Model Softw 16(3):195–231

[12] Lee DJ, Howitt RE (1996) Modelling regional agricultural production and salinity control alternatives for water quality policy analysis. Am J Agric Econ 78(1):41–53

[13] Ji Z-G (2008) Hydrodynamics and water quality: modelling rivers, lakes, and estuaries. Wiley-Interscience, pp 704

[14] Abbaspour K, Schuol J. Autocalibration in hydrologic modeling: using SWAT2005 in small-scale watersheds. *Environmental Model- ling & Software*, 2008, 23(4): 422–434

[15] Arnold S L, Neitsch J. Soil and water assessment tool theoretical documentation. 2009

[16] Chen Y, Shuai J, Zhang Z, Shi P, Tao F. Simulating the impact of watershed management for surface water quality protection: a case study on reducing inorganic nitrogen load at a watershed scale. *Ecological Engineering*, 2014, 62: 61–70

[17] Yang C, Kuo J, Lung W, Lai J, Wu J. Water quality and ecosystem modeling of tidal wetlands. *Journal of Environmental Engineering*, 2007, 133(7): 711–721
[18] Geza M, Poeter E P, McCray J E. Quantifying predictive uncertainty for a mountain-watershed model. *Journal of Hydrology*, 2009, 376 (1): 170–181
[19] Reference Manual. MIKE 11 – a modeling system for rivers and channels. *Danish Hydraulic Institute*, 2009
[20] Refsgaard J C, Knudsen J. Operational validation and intercompar- ison of different types of hydrological models. *Water Resources Research*, 1996, 32(7): 2189–2202
[21] Thompson J R, Sørenson H R, Gavin H, Refsgaard A. Application of the coupled MIKE SHE/MIKE 11 modelling system to a lowland wet grassland in southeast England. *Journal of Hydrology*, 2004, 293(1): 151–179
[22] Liu H L, Chen X, Bao A M, Wang L. Investigation of groundwater response to overland flow and topography using a coupled MIKE SHE/MIKE 11 modeling system for an arid watershed. *Journal of Hydrology*, 2007, 347(3): 448–459
[23] Soon S, Park L. A water quality modeling study of the Nakdong River, Korea. *Ecological Modelling*, 2002, 152(1): 65–75
[24] Palmieri V, de Carvalho R J. Qual2e model for the Corumbataí River. *Ecological Modelling*, 2006, 198(1): 269–275
[25] Bailey R T, Ahmadi M. Spatial and temporal variability of in-stream water quality parameter influence on dissolved oxygen and nitrate within a regional stream network. *Ecological Modelling*, 2014, 277: 87–96
[26] Salvetti R, Acutis M, Azzellino A, Carpani M, Giupponi C, Parati P, Vale M, Vismara R. Modelling the point and non-point nitrogen loads to the Venice Lagoon (Italy): the application of water quality models to the Dese-Zero basin. *Desalination*, 2008, 226(1–3): 81– 88
[27] Barnwell T O, Johanson R.“HSPF: a comprehensive package for simulation of watershed hydrology and water quality.” Nonpoint pollution control– tools and techniques for the future. *Proceedings of a Technical Symposium*, 1981: 135–153.
[28] Crawford N H, Linsley R K. Digital Simulation in Hydrology Stanford Watershed Model 4. *1966*
[29] Kim Y, Chung E S. An index-based robust decision making framework for watershed management in a changing climate. *Science of the Total Environment*, 2014, 473–474: 88–102
[30] Fonseca A, Botelho C, Boaventura R A, Vilar V J. Integrated hydrological and water quality model for river management: a case study on Lena River. *Science of the Total Environment*, 2014, 485: 474–489
[31] Cole T M, Buchak E M. CE-QUAL-W2: a two-dimensional, laterally averaged, hydrodynamic and water quality model. User Manual (Version 2.0). *Army Engineer Waterways Experimental Station Vicksburg Ms Environmental Lab*, 1995
[32] Hamrick J M. User’s manual for the environmental fluid dynamics computer code. *Department of Physical Sciences, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary*, 1996
[33] Ji Z G, Morton M R, Hamrick J M. Wetting and drying simulation of estuarine processes. *Estuarine, Coastal and Shelf Science*, 2001, 53 (5): 683–700
[34] Xie R, Wu D, Yan Y, Zhou H. Fine silt particle pathline of dredging sediment in the Yangtze River deepwater navigation channel based on EFDC model. *Journal of Hydrodynamics*, 2010, 22(6): 760–772
[35] Liu X, Huang W. Modeling sediment resuspension and transport induced by storm wind in Apalachicola Bay, USA. *Environmental Modelling & Software*, 2009, 24(11): 1302–1313
[36] Franceschini S, Tsai C W. Assessment of uncertainty sources in water quality modeling in the Niagara River. *Advances in Water Resources*, 2010, 33(4): 493–503
[37] Wu G, Xu Z. Prediction of algal blooming using EFDC model: case study in the Daoxiang Lake. *Ecological Modelling*, 2011, 222(6): 1245–1252
[38] Xu H, Lin J, Wang D. Numerical study on salinity stratification in the Pamlico River Estuary. *Estuarine, Coastal and Shelf Science*, 2008, 80(1): 74–84