

行政院國家科學委員會補助專題研究計畫成果報告

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河川水理水質與生態模式—
整治工程對生態環境影響之探討(二)

計畫類別：個別型計畫 整合型計畫

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計畫主持人：柳文成

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- 赴國外出差或研習心得報告一份
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- 國際合作研究計畫國外研究報告書一份

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河川水理水質與生態模式—整治工程對生態環境影響之探討(二)
Hydrodynamics, Water Quality and Ecological Model in River System—An
Investigation of the Influence on Ecological Environment Due to Cleanup
Engineering (II)

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一、中文摘要

淡水河系為台灣最大的感潮河川，其集水面積包括大台北都會區，主要之三大支流為大漢溪、新店溪及基隆河。垂直二維數值模式經修改及擴展以涵蓋主流與支流之效應，並應用於淡水河系。

本研究於河口數值模式中建立簡單的計算架構，以涵蓋河口濕地與主河道間之交互作用，模式並應用於淡水河河口與關渡濕地。模式以現有的資料予以檢定與驗證，並用以模擬不同上游流量之作用下，關渡濕地之水質狀況。結果顯示本模式之處理方式不僅簡單並可反映出主河道與濕地間水與物質交換之物理與生化作用程序，模式未來可作為河口濕地生態環境規劃、保護及棲息環境復育之有效工具。

關鍵詞：河口濕地、水質、側蓄留區、檢定與驗證、模式應用。

Abstract

The Tanshui River system is the largest estuarine system in Taiwan, with drainage basin including the capital city of Taipei. It consists of three major

tributaries: the Tahan Stream, Hsintien Stream and Keelung River. A vertical two-dimensional numerical model is refined and expanded to handle tributaries as well as the main stem of an estuarine system, and applied to the Tanshui River estuarine system.

A simple computation framework is applied to include estuarine wetland and their interaction with main channels in estuarine modeling. The concept and the model implementation of the scheme are explained using a vertical two-dimensional model of estuarine hydrodynamics and water quality. The model was applied to the Tanshui River estuary and Kuan-Du wetland. The model is calibrated and verified by the available measured data. Simulations are also conducted for various upstream freshwater discharges to predict water quality in the main channel and estuarine wetland. The results show that the inclusion of estuarine wetland in a water-quality model not only provides a framework for computing water-quality conditions but also accounts for the interaction between wetland and main channel. The model provides a useful tool for environmental planning, protection and proposed wetland

restoration works.

Keywords: Estuarine Wetland, Water Quality, Side Storage Area, Calibration and Verification, Model Application.

INTRODUCTION

Wetlands are among the most important ecosystems on Earth. In the great scheme of things, the swampy environment of the carboniferous period and preserved many of the fossil fuels on which we now depend. In more recent biological and human time periods, wetlands are valuable as sources, sinks, and transformers of a multitude of chemical, biological, and genetic materials. Although the value of wetlands for fish and wildlife protection has been known for several decades, some of the other benefits have been identified more recently. Wetlands are sometimes described as "the kidneys of the landscape" because of the functions as the downstream receivers of waste from both natural and human resources. They have been found to cleanse polluted waters, prevent floods, protect shorelines, and recharge groundwater aquifers. Wetlands have also been called "biological supermarkets" for the extensive food chain and rich biodiversity they support. They play major roles in the landscape for providing unique habitats for a wide variety of flora and fauna [1]. Unfortunately, many wetlands have been converted to agricultural fields, altered for port development, or filled for industrial, commercial and residual development [1, 2]. Those wetland areas which still remain are faced with deteriorating water quality and subsequent changes in ecosystem function and structure [3, 4]. The current interest in the construction and restoration of wetlands had led to the need to understand the physical, chemical, and biological processes that control such ecosystems.

The total area of the natural wetlands in Taiwan is 11896 ha, that include the coastal land 1356 ha and the inner wetlands 540 ha. The major part area of the coastal wetland in Taiwan are scattered in western coastal area where are rivers and ocean cross. There are five types of the coastal wetlands: 1. The swamp lands of mangroves. 2. The sticky mass of earth. 3. The grass wetlands. 4. The coastal sandy area. 5. The lake in the coastal area. The ecological functions are: high productivity, high species diversity and as the middle station to rest for the birds. The protective functions are: to protect the coastal area, to prevent the flooding and to preserve the waters, to supply the recreational and research area. Before, the wetlands have been neglected and have changed to be as the industry, agricultural and fishing area. At present, the environmental protection issues have been very important. Due to the large areas of wetlands have been developed and the interruptions by human beings, so the most emergent and important issues is to consider how to conserve the coastal wetlands in Taiwan [5].

Wetlands such as salt marshes and mangrove swamps are continually exchanging tidal waters with adjacent estuaries. The water and material exchanges between the main body of estuary and its fringing wetland exert great influence on the ecological landscape of the wetland. Therefore, hydrodynamic and water quality conditions in the adjacent main body of estuary are majors factors to be considered in planning the protection or restoration of estuarine wetland.

In this study, we propose a simple computational framework to include mangrove wetland and their interaction with adjacent main channels in estuarine modeling. The scheme, which treats mangrove wetland as temporary side storage areas, accounts for the water and material exchanges

between mangrove wetland and main channels as the tide rises and falls, and for the biogeochemical processes affecting non-conservative substances such as water quality parameters in mangrove wetland. A vertical two-dimensional numerical model of estuarine hydrodynamics and water quality described in Hsu et al. [6, 7] and Liu [8] was used to explain the concept and the model implementation of the proposed method. The model is first calibrated and verified by the existing available observational data. Then, water quality simulations in the main channel and mangrove wetland are presents under various hydrological conditions.

STUDY AREA

The Tanshui River is the largest tidal river in Taiwan. The entire river system has a drainage area of 2726 km^2 , and a total channel length of 327.6 km . It consists of three major tributaries: the Tahan Stream, Hsintien Stream and Keelung River (Figure 1). The downstream reaches of all three tributaries are affected by tide. The Kuan-Du estuarine wetland is situated at the confluence of the Keelung River and the Tanshui River, lying on an alluvial fan which accumulates deposition of suspended materials, nutrients, and biological debris flushing from all three tributaries. The mean tidal ranges at the Tanshui river mouth and at the location near the Kuan-Du wetland are 222 cm and 226 cm, respectively. The mean discharges at the tidal limits of the three major tributaries are 62.1 m^3/s , 72.7 m^3/s and 26.1 m^3/s for the Tahan Stream, Hsintien Stream and Keelung River, respectively. Tidal seawater, which can intrude into the upper estuary approximately 25 km from the river mouth, can mix well with the river water during high tide, but mixing is only partial during low tide [9]. The mean annual river discharge and suspended

particulate matter transport over the last 40 years have been approximately $7044 \times 10^6 m^3/year$ and $11.45 \times 10^6 tons/year$, respectively [10].

Six million people, over a quarter of Taiwan's entire population, reside in the catchment area of the Tanshui River system. The river system receives untreated domestic discharge and both treated and untreated industrial effluent from its tributaries; thus, it is heavily polluted by nutrients and organic materials. It is estimated that approximately 1790 MI/day of domestically treated and untreated, mostly untreated, sewage is input to the Tanshui River system [11]. Because it receives the sewage discharge and waste effluence from industries, the upper estuary is suboxic and gradually becomes oxic in the lower estuary where the tidal seawater intrudes [12].

Because of its vast area and topographic effects, the Kuan-Du wetland forms a complicated environment of estuarine wetland, coastal wetland and inland wetland. It is the most important landscape among the twelve remaining estuarine wetlands in Taiwan. A dike of 3.5 m in height was constructed in 1968 to carve-out 85 % of the area for development. The dike was designed to protect against flood of five-year return period [13]. The wetland outside the dike is filled with mangroves that can tolerate higher salinity and form the typical tidal salt marsh ecosystem. The salt marsh has high species diversity and commensurate food sources and habitat types for wildlife and is very sensitive to human impact.

MODEL DESCRIPTION

The original version of the model was developed by Park and Kuo [14, 15] and then was refined and expanded to handle tributaries and the mainstem of an estuarine system and applied to the Tanshui River estuarine system.

The vertical two-dimensional finite difference model, consisting of linked hydrodynamic model is based on the principles of conservation of volume, momentum, and conservative substance (such as salt). The water-quality model is based on the principles of conservation of eight interlinked water-quality state variables: dissolved oxygen, chlorophyll *a*, carbonaceous biochemical oxygen demand, organic nitrogen, ammonia nitrogen, nitrite-nitrate nitrogen, organic phosphorus, and phosphate (ortho) phosphorus. A full description of the model can be found in Park and Kuo [14, 15] and Liu [8].

The coupling framework proposed by Kuo and Park [16] is refined and adopted to the model for the Tanshui River system. In the estuarine model, the Kuan-Du wetland may be treated as temporary storage area with spatially constant water depth, function as a sink or source of momentum and mass to the main channel as the tide rises or falls, respectively. The water level in the wetland is assumed to rise and fall instantly with the main channel, and the inundated area is assumed to increase linearly with water level as it rises above a certain level. Since the volume exchange between the wetland and the main channel is determined by the temporal variation of water surface level in the wetland, and the water depth in the wetland is small, the momentum and mass exchanges are assumed to occur only at the top layer of the vertical two-dimensional model. At the rising tide, the wetland serves as a sink for both momentum and mass.

MODEL CALIBRATION AND VERIFICATION

Calibration and verification are far more difficult for the water quality model than for the hydrodynamic model,

due to the large number of water quality state variables and biochemical reaction coefficients involved. Since the model predictions will change depending upon the selection of the values of biochemical coefficients, the water quality model should employ consistent coefficient values for different simulation runs. That is, the coefficient values should be transferable for the model predictions to compare with independent sets of field observations.

Field data, including long-term time-series result of water quality variables at different stations in the river collected by Taiwan EPA from 1994 to 1996 were used to calibrate and verify of the water quality model. They include the environmental conditions such as water temperature, downstream boundary conditions, waste loadings including non-point and point sources.

The model was conducted for one-year simulation. The daily averages of the model results are compared with the values from field observations of different stations. The measured data in 1994 and 1995 are used for calibration and compared with model computation. Figure 2 presents the model verification in 1996. The results show very high nutrient concentrations including nitrogen and phosphorus, rendering the dissolved oxygen deficiency in the river. Figures show that model results and field measurements were in generally good agreement. Discrepancies were often attributable to observance of the consistency principle between calibration and verification rather than to failure to curve-fit the model results to the field data; some differences, however, did exist between the model results and the field measurements. The changes of variations in model results were generally smaller than those in the field data, because the model calculated the lateral average concentrations while the field data were point measurements,

and also because of the random variability inherent to natural system.

Figure 2 provides a qualitative comparison of model predictions and field observations. This tradition assessment of model accuracy, the perceived agreement between predictions and observations, depends upon the viewpoint and experience of assessors. In order to render the evaluation of models less subjective, quantitative assessment of model accuracy are desirable. No single measure of set of measures is universally applicable for this purpose. The selection of appropriate measures is dependent upon the quantity and quality of the field data used and upon the nature of the model predictions. In the present study scatterplots, the root-mean-square error (RMS) and mean absolute error (E) are used.

$$RMS = \sqrt{\frac{1}{2} \sum_{i=1}^n (P_i - O_i)^2} \quad (1)$$

$$E = \frac{1}{n} \sum_{i=1}^n |P_i - O_i| \quad (2)$$

Where P_i is the i th prediction (daily average), O_i is the i th observation and n is the number of observations.

Scatterplots for point-by-point comparison of predictions and observations at Kuan-Du Bridge are presented in Figure 3. A solid, diagonal line indicates the one-to-one correspondence. Magnitude of water quality parameters can range from zero (limit value) to an unbounded value at the higher end.

MODEL RESULTS AND DISCUSSIONS

The calibrated and verified model was employed to investigate the water quality in main channel and Kuan-Du wetland under mean freshwater discharges and Q_{75} low flows at the upstream boundaries. Upstream

boundary conditions were specified with daily freshwater discharges at Cheng-Ling Bridge (Tahan Stream), Hsui-Lang Bridge (Hsintien Stream), and Wu-Tu Station (Keelung River). The mean discharges at the tidal limit of the three major tributaries are $62.1 \text{ m}^3/\text{s}$, $72.7 \text{ m}^3/\text{s}$, and $26.1 \text{ m}^3/\text{s}$ for the Tahan Stream, Hsintien Stream, and Keelung River, respectively. The Q_{75} flows at upstream boundaries are $8.15 \text{ m}^3/\text{s}$, $20.2 \text{ m}^3/\text{s}$, and $3.61 \text{ m}^3/\text{s}$ for the Tahan Stream, Hsintien Stream, and Keelung River, respectively. For the water quality conditions at the upstream and downstream boundaries, historical data of water quality field measurements was collected and analyzed. The same values are specified for the boundaries under mean freshwater discharges and Q_{75} flows. A nine-constituent tide was used for the model application when a synthetic tide was employed to specify the downstream boundary condition. Nine constituents are M_2 (12.42 hr), S_2 (12 hr), N_2 (12.9 hr), K_1 (23.93 hr), S_a (8765.32 hr), O_1 (25.82 hr), K_2 (11.97 hr), P_1 (24.07 hr), and M_4 (6.21 hr). Amplitudes and phases of nine tidal constituents were specified to generate surface elevation as the downstream boundary condition for model simulation.

Figure 4 presents the model results in concentration in the Keelung River off the Kuan-Du wetland. The dissolved oxygen and chlorophyll concentrations in the main channel are noticeably different with nitrogen concentration. The dissolved oxygen and chlorophyll concentrations under mean flow conditions are higher than that under Q_{75} low flows, and nutrients under mean flow conditions are lower than that under Q_{75} low flows, because the pollutant should be diluted during high

freshwater discharge. Figure 5 shows the concentration in the Kuan-Du wetland. Maximum dissolved oxygen concentration in Kuan-Du wetland compared to the concentration in the channel shows mass exchanges between wetland and main channel, result in high dissolved oxygen in the Kuan-Du wetland. The model, therefore, cannot simulate the condition in wetland correctly without proper simulation of main channel conditions. Many modeling efforts that study biochemical processes in shallow waters have not included the main channel conditions as a boundary condition. The dependency of wetland conditions on main channel conditions limit the general applicability of such models for management purposes. For example, explicit modeling of main channel conditions and of exchange between wetland and main channel is essential to project the potential impacts on the water-quality conditions in wetland of any changes in nutrient loadings into the system.

CONCLUSIONS

A vertical two-dimensional estuarine model for the Tanshui River system is developed and used to simulation water quality of the Kuan-Du wetland and main channel. A simple computational framework to include mangrove wetland and their interaction with main channels in estuarine modeling is presented. The proposed scheme treats wetland as temporary storage areas. It account for the water and material exchange between wetland and main channels as the tide rises and falls, and the biogeochemical processes for nonconservative substances such as water-quality variables in wetland. The water quality model has been calibrated and verified using field data from 1994 to 1996. Considering the random variability inherent in natural systems and the goal of consistency in calibrated coefficients, the agreement between

predictions and field observations is more than satisfactory. In general, the agreement between predictions and observations depends upon both quality and quantity of input data, and the nature and number of observations.

The calibrated and verified model is further used to simulation water quality in the main channel and mangrove wetland under various hydrological conditions. The dissolved oxygen and chlorophyll concentrations under mean flow conditions are higher than that under Q_{75} low flows, and nutrients under mean flow conditions are lower than that under Q_{75} low flows, because the pollutant should be diluted during high freshwater discharge. Maximum dissolved oxygen concentration in Kuan-Du wetland compared to the concentration in the channel shows mass exchanges between wetland and main channel, result in high dissolved oxygen in the Kuan-Du wetland. The difficulty is especially so because most of the monitoring programs in estuaries have been forced mainly on the main channels, and thus little field data are available for water-quality processes and variables in the wetland, which may be quite different from those in main channel. Further field surveys for estuarine modeling, therefore, should be designed to include measurement of water-quality condition in the wetland. However, the model provides the useful tool to predict water-quality conditions in the wetland, using with a simple computational scheme.

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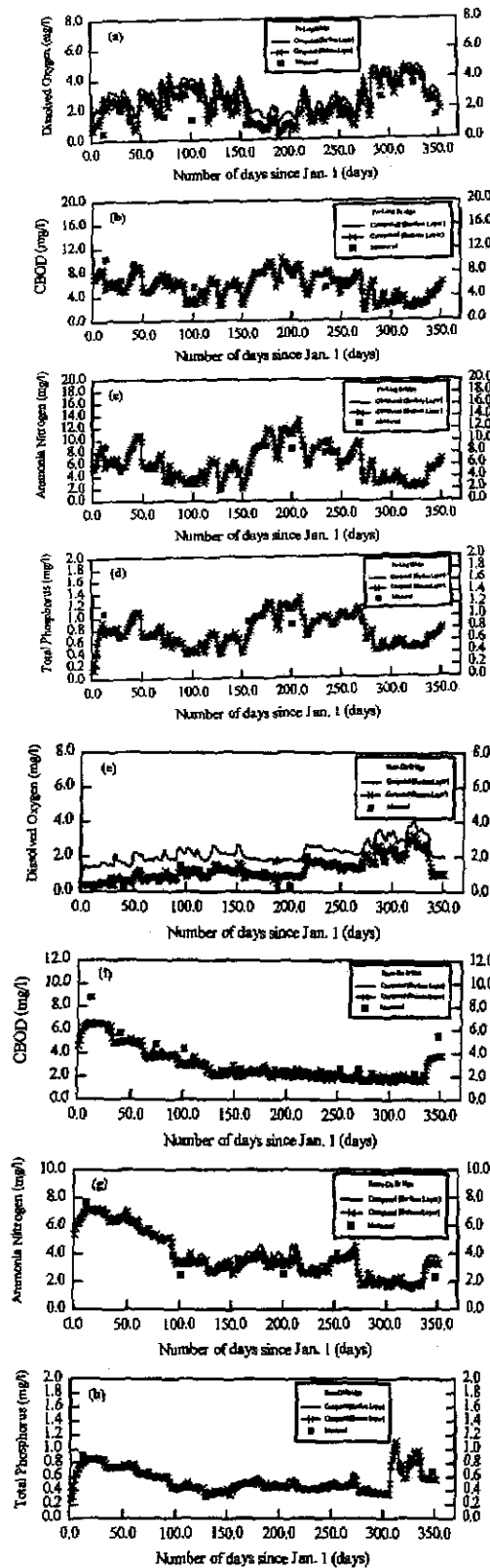


Figure 2. Model verification results at Pa-Ling Bridge (Keelung River) (a)-(d) and Kuan-Du Bridge (Tanshui River) (e)-(h) in 1996.

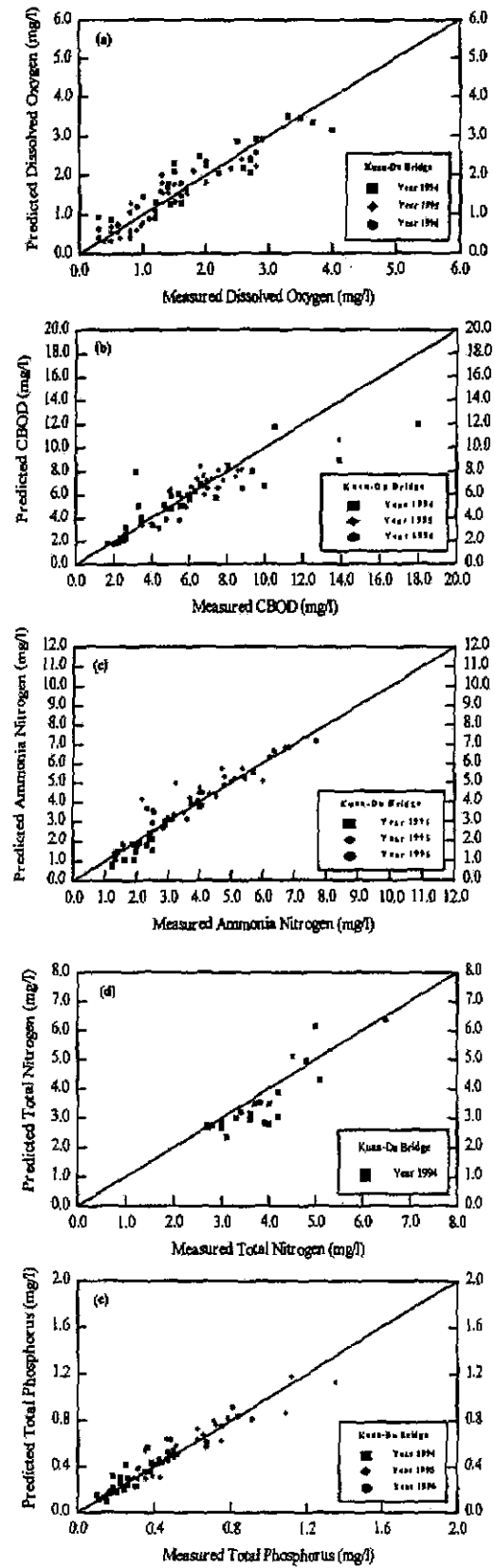


Figure 3. Scatterplots, RMS errors, an mean absolute errors for model calibration and verification at Kuan-Du Bridge (Tanshui River).

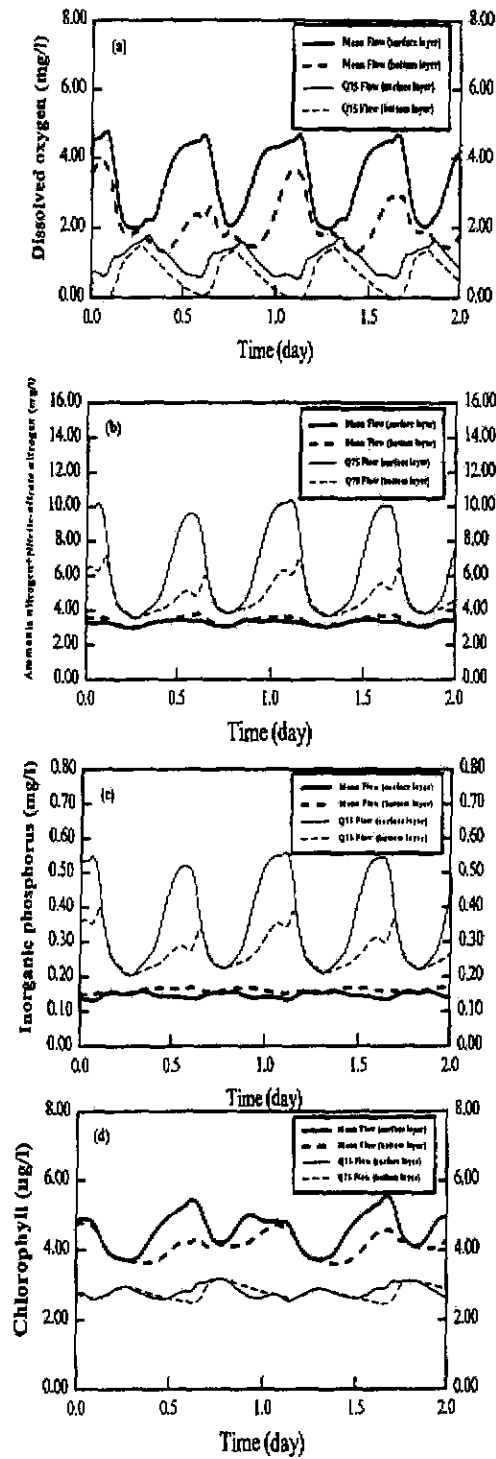


Figure 4. Model prediction in the Keelung River off the Kuan-Du wetland for mean and Q_{75} flow conditions.

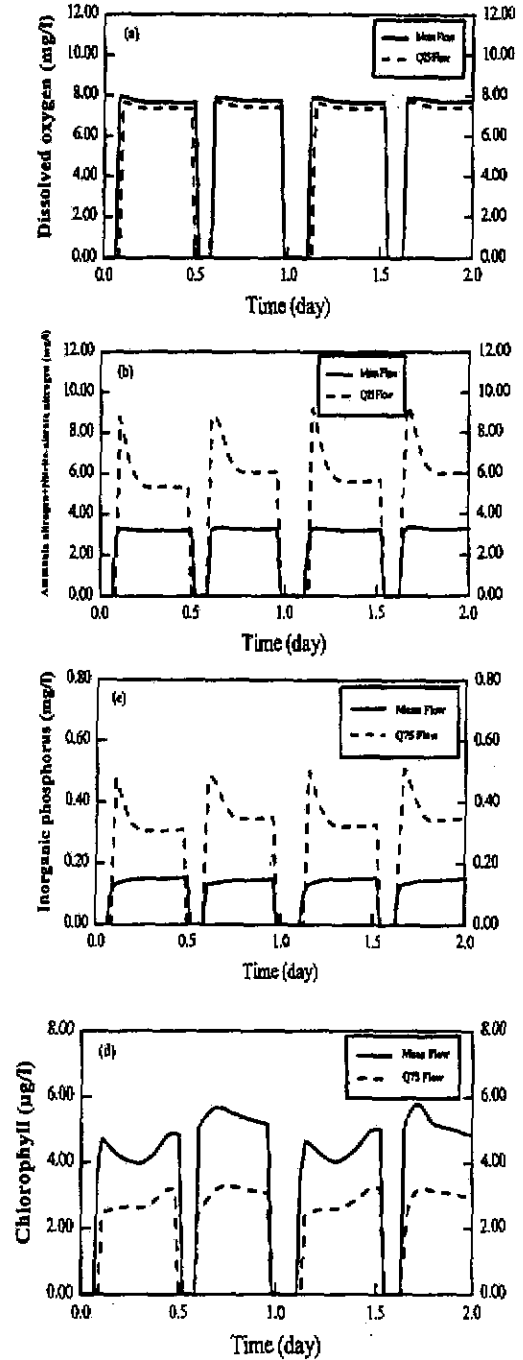


Figure 5. Model prediction of the concentration in the Kuan-Du wetland for mean and Q_{75} flow conditions.