APPLICATION OF A HYDRODYNAMIC WATER QUALITY MODEL IN SUNGAI JOHOR ESTUARY

MAZNAH BINTI ISMAIL

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ALHAMDULILLAH

All Praise To Allah, Creator Of This Universe

Thanks For The Precious Iman & Islam You Blessed On Me

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All This Hardship I Dedicate To Some Special People In My Life

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ABSTRACT

Sungai Johor estuary is a vital water body in the south of Johor and greatly affects the water quality in the Johor Straits. In the development of the hydrodynamic and water quality models for Sungai Johor estuary, the Environmental Fluid Dynamics Code (EFDC) model was selected. In this application, the EFDC hydrodynamic model was configured to simulate time varying surface elevation, velocity, salinity, and water temperature. The EFDC water quality model was configured to simulate dissolved oxygen (DO), dissolved organic carbon (DOC), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), phosphate (PO_4), and Chlorophyll *a*. The hydrodynamic and water quality model calibration was performed utilizing a set of site specific data acquired in January 2008. The simulated water temperature, salinity and DO showed good and fairly good agreement with observations. The calculated correlation coefficients between computed and observed temperature and salinity were lower compared with the water level. Sensitivity analysis was performed on hydrodynamic and water quality models input parameters to quantify their impact on modeling results such as water surface elevation, salinity and dissolved oxygen concentration. It is anticipated and recommended that the development of this model be continued to synthesize additional field data into the modeling process.

ABSTRAK

Muara Sungai Johor merupakan salah satu sungai yang penting di selatan Johor dan sangat mempengaruhi kualiti air di Selat Johor. Dalam pembangunan model hidrodinamik dan kualiti air bagi sistem muara Sungai Johor, model *Environmental Fluid Dynamic Code* (EFDC) telah dipilih. Dalam aplikasi model hidrodinamik EFDC ini, simulasi ketinggian permukaan, halaju, dan kemasinan air dapat diukur. Model kualiti air EFDC pula dapat mengukur beberapa parameter seperti oksigen terlarut (DO), karbon organik terlarut (DOC), permintaan oksigen kimia (COD), nitrogen ammonia (NH_3-N), nitrogen nitrat (NO_3-N), fosfat (PO_4), dan Chlorophyll *a*. Kalibrasi model hidrodinamik dan kualiti air dilakukan dengan menggunakan set data di tapak dalam bulan Januari 2008. Simulasi suhu air, kemasinan air dan oksigen terlarut menunjukkan hasil yang baik dengan hasil cerapan. Pengiraan korelasi di antara model dan cerapan suhu dan kemasinan adalah lebih rendah berbanding dengan paras air. Analisis kepekaan dijalankan terhadap parameter masukan model hidrodinamik dan kualiti air untuk mengukur kesan terhadap hasil permodelan seperti paras air permukaan, kemasinan dan konsentrasi oksigen terlarut. Adalah diharapkan agar pembangunan model ini akan diteruskan dengan mengumpulkan lebih banyak data lapangan dalam proses permodelan.

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LIST OF ABBREVIATIONS

AME	Absolute mean error
ASCE	American Society of Civil Engineers
BOD	Biochemical Oxygen Demand
CE-QUAL-ICM	Three-Dimensional Eutrophication Model
CE-QUAL-W2	Two-Dimensional, Laterally Averaged Hydrodynamic and Water Quality Model
CH3D-WES	Curvilinear Hydrodynamics in 3-Dimensions Waterways Experiment Station
COD	Chemical oxygen demand
DID	Department of Irrigation and Drainage
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DOE	Department of Environment
DYNHYD5	Link Node Tidal Hydrodynamic Model
EFDC	Environmental Fluid Dynamic Code
EPA	Environmental Protection Agency
HABs	Harmful algal blooms
HEM-3D	Three dimensional hydrodynamic eutrophication model
INWQS	Interim National Water Quality Standards for Malaysia
ME	Mean error
N	Nitrogen

NBOD	Nitrogenous Biochemical Oxygen Demand
NH^{+4}	Ammonium ions
NH_3-N	Ammoniacal Nitrogen
NO^{-3}	Nitrate ions
NO_3-N	Nitrate Nitrogen
P	Phosphorus
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biophenyls
PO_4	Inorganic Phosphorus
PO_4^{-3}	Inorganic Phosphate ions
POM	Princeton Ocean Model
QUAL-2E	Enhanced Stream Water Quality Model
RIVMOD-H	River Hydrodynamic Model
RMSE	Root mean square error
SOD	Sediment oxygen demand
SS	Suspended Solids
TMDLs	Total Maximum Daily Loads
TOC	Total Organic Carbon
USACOE	United State Army Corps of Engineer's
UTM	Universiti Teknologi Malaysia
WASP5	Water Quality Simulation Program
WQI	Water Quality Index

LIST OF SYMBOLS

u	=	velocity component in the x-direction
v	=	velocity component in the y-direction
w	=	velocity component in the z-direction
x, y	=	curvilinear horizontal coordinates
K_x	=	turbulent diffusivities in the x-direction
K_y	=	turbulent diffusivities in the y-direction
K_z	=	turbulent diffusivities in the z-direction
S_C	=	internal and external sources and sinks per unit volume
κ	=	von Karman constant
Δ_l	=	dimensionless thickness of the bottom layer
z_o	=	dimensionless roughness height
b	=	buoyancy
ρ	=	actual water density
ρ_o	=	reference water density
ρ_a	=	air density
ρ_w	=	water density
c_s	=	wind stress coefficient
c_b	=	bottom drag coefficient
Uw, Vw	=	component of the wind velocity at 10 meter above the water surface
A_H	=	horizontal turbulence mass diffusion coefficient
A_b	=	vertical turbulence mass diffusion coefficient
R_c	=	physical and biogeochemical sources and sinks
Q_H	=	volume sources and sinks including rainfall, evaporation, infiltration, and lateral inflows and outflows having negligible momentum fluxes
m_x , m_y	=	scale factors of the horizontal coordinates
w	=	vertical velocity in the stretched vertical coordinate

z_s*	=	physical vertical coordinate of the free surface
z_b*	=	physical vertical coordinate of the bottom bed
H	=	total water column depth
ϕ	=	free surface potential
Fe	=	effective Coriolis acceleration
Q	=	horizontal momentum diffusion terms
Av	=	vertical turbulent viscosity
ρ_{atm}	=	atmospheric pressure
u_*	=	shear velocity
c_b	=	bottom stress coefficient
U	=	flow velocity at the bottom layer
Av	=	viscosity
Kv	=	turbulent diffusivity
Rq	=	turbulent intensity Richardson Number

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CHAPTER 1

INTRODUCTION

1.1 Introduction

An estuary is a semi-enclosed coastal body of water with one or more rivers or streams flowing into it, and with a free connection to the open sea (Pritchard, 1967). They are affected by both marine influences, such as tides, waves, and the influx of saline water; and riverine influences, such as flows of fresh water and sediment. As a result they may contain many biological niches within a small area, and so are associated with high biological diversity.

Estuaries face a host of common challenges. As more people flock to the shore, we are upsetting the natural balance of estuaries and treating their health. We endanger our estuaries by polluting the water and building on the lands surrounding them. These activities can contribute to unsafe drinking water and beach, closing of shellfish bed, harmful algal blooms, declines in fisheries, loss of habitat, fish kills, and a host of other human health and natural resource problems.

Although each of the estuaries in our country, Malaysia is unique, all of them face similar environmental problems and challenges, such as over enrichment of nutrients, contamination of pathogen, toxic chemicals, alteration of freshwater inflow, loss of habitat, declines in fish and wildlife, and introduction of invasive species. While no regional or national conclusions can be drawn about the overall health of estuaries in Malaysia, these problems tend to cause declines in water quality, living resources, and overall ecosystem health.

With regard to tidal estuaries and given specific input, such as stream flows, engineers and hydrologists use hydrodynamic models to predict outputs, such as water surface elevations and velocities. In addition, given hydrodynamics and contaminant loading rates, they make use of water quality models to predict contaminant concentrations. The hydrodynamic and water quality models utilization consist of a detailed set of equations that serve to represent complex physical processes. However, as the number of required equations to describe the processes in question increases, the computational time and model complexity also increases. As a result, numerical models have been developed to aid in the solution of complex process equations.

Computer models for simulating estuary hydrodynamics and water quality have existed for more than 40 years (Chapra, 1997). Significant improvements have been made to the original computer models, therefore, improving the quality of model outputs. Today's computer models allow users to simulate in one, two, and three dimensions. In addition, they enable users to model water bodies that are either in steady state or dynamic systems. Model solution techniques have also been improved and the two most commonly employed are finite differences or finite elements. As a result of these improvements, users are now applying computer models to larger and larger estuary systems, in order to estimate hydrodynamics and, more importantly, water quality.

In order to advance the process of improving water quality assessment techniques within an estuarine system, a computer model will be necessary to estimate river and estuarine hydrodynamics and contaminant concentrations (Liu et al., 2008). However, since the model study area is tidally influenced, the model utilized will have to take into consideration the impacts of the flood and ebb tides that occur multiple times a day. In addition, the model should be fairly straightforward in terms of setup, and the computational time should not be excessive while using a current desktop computer. The model should be able to simulate a dynamic system, and it should employ a robust numerical solution technique, such as finite elements or finite differences.

A multifunction surface water modeling system, which includes hydrodynamic, sediment-contaminant and water quality models, was developed and applied for Sungai Johor estuary. The hydrodynamic model, based on the principles of conservation of volume, momentum and mass, predicts surface elevation, current velocity and salinity. The water quality model, based on the conservation of mass balance, predicts seven parameters, such as dissolved oxygen, COD, DOC, ammonia nitrogen, nitrate nitrogen, total phosphate and Chlorophyll *a*. The model equations were solved using finite difference scheme. Model parameters were estimated from existing and collected datasets during initial setup. A calibration time period was used to modify and refine the model parameters.

1.2 Problem Statement

River and marine water quality monitoring in Malaysia has been conducted by Malaysian Department of Environment (DOE) since 1978, primarily to establish the status of water quality, detect water quality changes and identify pollution sources. In 2007, there were a total of 1063 water quality monitoring stations located within 143 river basins through out Malaysia. This involves routine monitoring at predetermined stations, in-situ and laboratory analysis, and data interpretation in terms of their physic-chemical and biological characteristics. River water quality appraisal is based on Water Quality Index (WQI) involving parameters such as Dissolved Oxyen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (NH_3N), Suspended Solids (SS) and pH. The WQI serves as a basis for assessment of a water course in relation to pollution categorization and designated classes of beneficial uses in accordance with the Proposed Interim National Water Quality Standards for Malaysia (INWQS). The DOE maintains 39 monitoring stations for Sungai Johor river basin. DOE (2007) reported that there were a total of 51 marine water quality monitoring stations located at Johor estuary and coastal area.

Dr. Noor Baharim, lecturer in the Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai said a significant increase of freshwater inflow into the estuarine areas during flash flood at Kota Tinggi has affected the aquatic life for up to three weeks. Many of the fish die or swim to other river resulting in dwindling catch for the local fishermen. He said the nutrient level of the water samples collected from the Straits of Johor showed there was a risk of algal bloom in the region. There is an increasing concern of oversupply of nutrients from multiple sources in Sungai Johor estuary. This has ecological effects on the shallow coastal and estuarine areas. These effects include decrease in dissolved oxygen, impacts on living resources and loss of aquatic habitat. Degraded water quality has adverse effects on critical habitats in Sungai Johor estuary such as seagrass, which is an essential food for dugong and many herbivorous fish (Land Clearing, Sand Mining Affect Rivers, 2007, April 16). Hence, there is the need for comprehensive and intensive baseline studies of the water quality in the Sungai Johor estuary in order to assess the impact of all existing and future developments on the ecology of the Sungai Johor estuarine and coastal waters.

1.2.1 Description of Study Area

Johor is the second largest state in Peninsular Malaysia with an area of 18,941 km^2. Sungai Johor is considered the main river in Johor. The river flows in a roughly north-south direction and empties into the Johor Straits. The water quality of Sungai Johor has been deteriorating with increasing levels of various pollutants. Besides, it persists to be silted and chocked by rubbish and wastes as a consequence of storage of enforcement by local-authorities. These contaminants eventually flow into Sungai Johor estuary, which are rich in habitats that provide spawning and feeding areas for fish and poultry.

The Johor estuarine system, an interconnected series of estuarine systems, is a vital water body in the Southern Johor as the South Gateway to Peninsular Malaysia. The estuary provides convenient and inexpensive navigation and transportation support for the economic activities in the area.

The Sungai Johor river basin is located at the southeastern tip of Peninsular Malaysia as shown in Figure 1.1. Sungai Johor has a total length of about 122.7 km with catchment area of 2636 km^2. The river originates from Gunung Belumut and Bukit Gemuruh in the north and flows to the southeastern part of Johor and finally into the Straits of Johor. The major tributaries of Sungai Johor are Sungai Sayong, Sungai Linggiu, Sungai Semanggar, Sungai Lebam, Sungai Seluyut and Sungai Tiram.

A great amount of pollutants from various sources, such as the sewerage network of the Johor Bahru, Pasir Gudang, Ulu Tiram, and Kota Tinggi cities, the industrial wastewaters from many industries in the surroundings, and agricultural wastewater containing fertilizers and pesticides are discharged into the Sungai Johor. The catchment is irregular in shape. The maximum length and breadth are 80 km an 45 km respectively. About 60% of the catchment is undulating highland rising to a height of 366 m while the remainders are lowland and swamps. The highland in the north is mainly jungle. In the south, a major portion had been cleared and planted with oil palm and rubber. The highland areas have granite soil cover consisting of fine to coarse sand and clay. The alluvium consists of fine sand and clay.

The catchment receives an average annual precipitation of 2470 mm while the mean annual discharge measured at Rantau Panjang (1130 km^2) were 37.5 m^3/s during the period 1963-1992. The temperature in the basin ranges from 21 ºC to 32 ºC. Due to the tidal influence, the Sungai Johor is an ideal study area for research on model implementation and the prediction of hydrodynamics and water quality in tidally influenced areas.

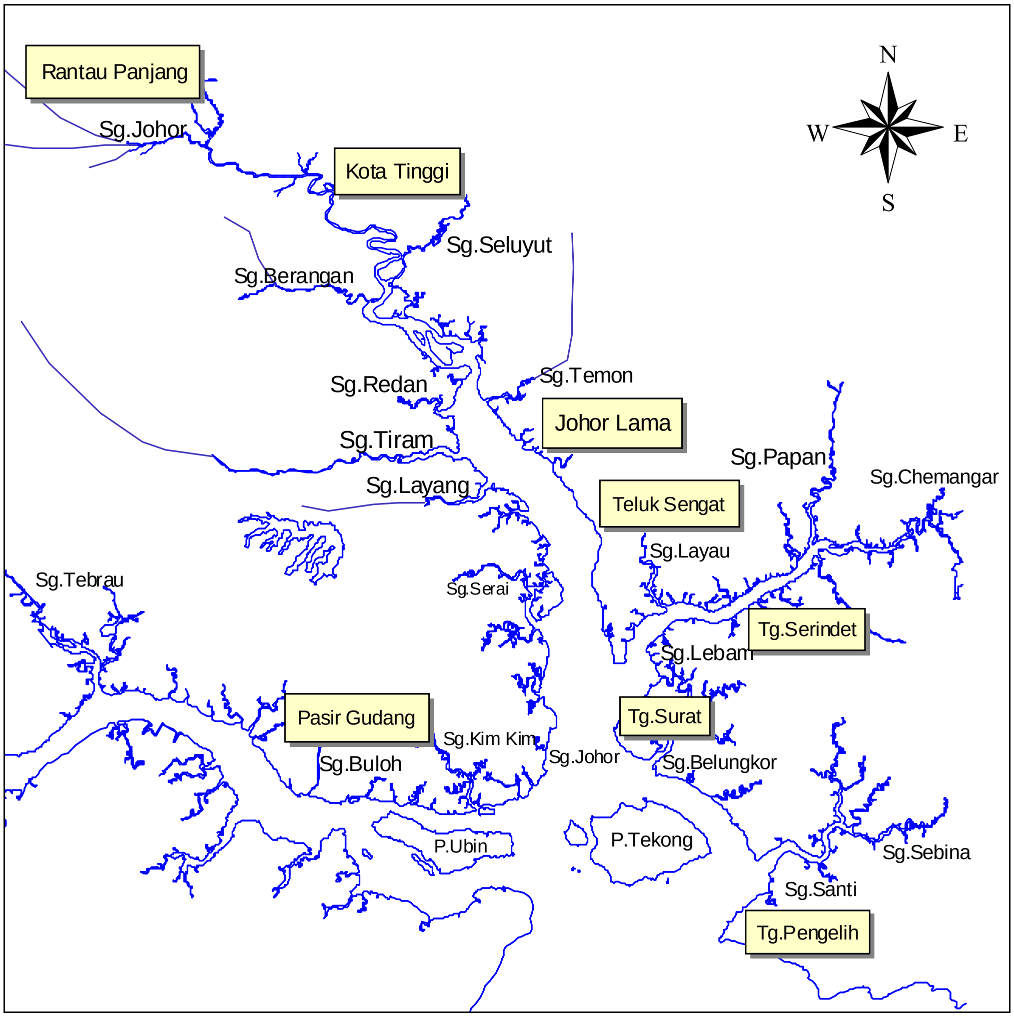

Figure 1.1: Map of Sungai Johor study area.

1.3 Objective of the Study

The primary purpose of the study is to apply EFDC hydrodynamic and water quality model to Sungai Johor estuarine system. The objectives of the study are listed as follows:

i. To calibrate the model utilizing historical data and field data collection.
ii. To do sensitivity analysis of input parameters of hydrodynamic and water quality model.

1.4 Scope of the Study

The scope of this research concentrates on developing hydrodynamic and water quality modeling tools for Sungai Johor estuarine system. These tools have been used to minimize the cost of analysis. This study was limited to the following scope of work to meet the specific objectives:-

i. To collect existing data and information relevant to the study area, Sungai Johor. The relevant data and information consist of bathymetry data, water level data, water quality data, fresh water inflow data, wind data, and temperature data.
ii. To analyze the result from the hydrodynamics and water quality model that will give a reasonable and practical results to real condition in Sungai Johor estuarine system.
iii. To develop hydrodynamic and water quality model that can be useful for the further development at Sungai Johor estuarine system.

1.5 Significance of Research

Estuarine flow and DO distribution are three dimensional in nature. To simulate these completely, a three dimensional model with time dependent momentum and continuity equations, mass balance equations with details description of the biochemical kinetics, and sources and sinks of all dissolved constituents are necessary. It seems that the state of the art computer technology enables us to do three dimensional simulations, particularly of hydrodynamics (Blumberg and Mellor, 1987). The current sampling capacity, however, cannot provide us with the quantity and quality of field data that are indispensable for the calibration and verification of the model, particularly the water quality model.

This hydrodynamic model was applied in the study to simulate the flow field and salinity distribution, and the corresponding water quality model was developed to simulate the distributions of DO and other related water quality parameters.

EFDC hydrodynamics and water quality modeling is applied in the Sungai Johor estuarine system. The recommendation is based on the following arguments:

i. EFDC model comprises an advanced three dimensional surface water modelling system for hydrodynamic and reactive transport simulation of rivers, lakes, reservoirs, wetland systems, estuaries and the coastal ocean.
ii. EFDC has sufficient hydrodynamic and water quality capability to model the fate and transport of dissolved oxygen and nutrients within tidal estuary.
iii. EFDC was originally developed at Virginia Institute of Marine Science as part of a long term research program to develop operational models for resource management applications in Virginia's estuarine and coastal waters (Hamrick, 1992).
iv. EFDC is a public domain with current users including universities, governmental agencies and engineering consultants.
v. EFDC can be used for long term simulation over many tidal cycles.