Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 1, No. 4, p. 43-47, 2011
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Systematic approach to modelling water quality in estuaries

Paul C Njoku

School of Engineering and Engineering Technology, Department of Environmental Technology

Federal University of Technology, Owerri and Archna Swati Njoku

Received: 18 June 2011
Revised: 17 July 2011
Accepted: 18 July 2011

Key words: Systematic approach modeling water quality estuaries

Abstract

This paper deals with systematic approach to modeling water quality in estuaries. Modelings of estuaries are based more on approximation than are usually used for fresh water river flow. This is due to many changes in estuaries bodies. Two dimensional model is applied suspended material observed.

Corresponding Author: Paul C Njoku ✉ paul_njoku2002@yahoo.com

Introduction

Since the prevailing velocity structure in river flows is generally one-dimensional (1-D) the governing hydrodynamic and solute transport equations written in 1-D form are usually used for modelling flow and water quality indicators in riverine systems. In estuarine and coastal waters, where a dominant flow direction does not exist, then depth averaged two-dimensional (2-D) models are generally applied for flow and water quality modelling. For many engineering projects both riverine and estuarine waters are involved and the main interest is to determine the impact of the various inputs discharging into the rivers on the estuarine and coastal water quality. Hence it is necessary that water elevations, velocities and water quality concentrations are calculated simultaneously in riverine and estuarine waters.

The mathematical models used in this project include a 1-D model, FASTER (Flow And Solute Transport in Estuaries and Rivers), and a 2-D model, DIVAST (Depth Integrated Velocity And Solute Transport).
The FASTER model, which can be used to simulate hydrodynamic, solute and sediment transport processes in well-mixed rivers and narrow estuaries, has been developed based on the solution of the St Venant equations through an implicit finite difference scheme, with a varying grid size over a space-staggered grid. The water quality module of this model was developed based on a finite volume solution of the advective diffusion equation proposed by Kashefipour and Falconer (1999).

DIVAST was developed for simulating hydrodynamic, solute and sediment transport processes in estuarine and coastal waters. The hydrodynamic module was developed based on the solution of the depth integrated Navier-Stokes equations. For the water quality and sediment transport module, the two-dimensional advective-diffusion equation was solved for a range of water quality indicators using the highly accurate ULTIMATE QUICKEST scheme (Lin and Falconer, 1997).

The faecal coliform (FC) bacteria group is indicative of organisms from the intestinal tract of humans and other animals. In recent years several investigators have used faecal coliform discharging through outfall and/or non-outfall sources to quantify the quality of bathing water and urban river waters (Wyer *et al*, 1997; Thackston and Murr, 1999). In modelling faecal coliform the decay term is generally expressed as a first order decay function. Several factors such as sunlight, temperature and salinity level may influence the population of the organisms in a water body and thus in reporting the decay rate sampling conditions are usually specified. In the literature there is a large variation in the range of decay rate values for faecal coliform. Anderson et al have reported the decay rate to be in a range of 0.08 to 2.0 day-1 for E.coli in seawater conditions; whereas Fujioka et al have reported that for faecal coliform the decay rate was in a range of 37-110 day-1 in seawater and for sun-light conditions. The faecal coliform decay rate was also reported in the range of 0.0 to 6.1 day-1 for different conditions of salinity and sunlight (Thomann and Mueller, 1987).

Systems approaches to modeling on water quality in estuaries have been studied. It is noted that modeling water quality in estuaries are based on the following conditions as stated below.

More complex geometries, Changes in width, Changes in depth, Variation in cross-section bed profile;
Two-directional flow
- Downstream freshwater flow
Upstream saline flow

• Wetting and drying of parts of the cross-sectional floor
• Density differences between freshwater and saline water
• More suspended sediment than freshwater systems
• More alluvial beds where sediment can become re-suspended
• Wave action generating currents at the surface

As such, not only is evaluation of the hydrodynamics more complex but the water quality, being dependent on hydrodynamics, is extremely complex due to the interaction of:
• Freshwater quality processes
• Reservoir quality processes
• Tidal/oceanic quality processes (salinity)

Material and methods

Many studies had been conducted on the issue of estuaries modeling in the environment.
Fischer (1979) considered turbulent mixing in estuaries (to be composed of:
• Vertical mixing with a coefficient (eddy velocity)
E= 0.07du* 1
• Transverse mixing with a coefficient
ə,= 0.15du*.................2
• Longitudinal dispersion, which is dependent on the freshwater input low and its momentum, the tidal interaction with the bathymetry and wind and local effects
• Dispersion by gravitational circulation, i.e. internal circulation driven by density variation and explained by an 'Estuarine Richardson number',
PgQf
= P bu³
and that the transition from strongly stratified to well-mixed estuaries is 0.08 < R < 0.8

Model setup

• Dispersion by tide and wind
• Dispersion by shear within the vertical velocity profile
Where, *d* = depth
U* = root mean square (rms) tidal velocity
Δp = density difference
Qf = freshwater flow
b = estuary average width
u = mean velocity

Model performance and application

The simplest model for longitudinal dispersion in an estuary is obtained by a mass balance of a conservative tracer.

əc əc = ə (KA əc)
ət + Qfəx əx (əx) + source or sink terms 3

Q;=freshwater flow rate
C=the tidal cycle average concentration
A=the cross-sectional area
K = the mixing coefficient within the tidal cycle

The above equation is written in a pseudo-steady state for time averaged over the tidal cycle. Equation solved analytically for the steady state case as

Uf əC = K ə²C – kC ə* əx² 4

Where Uf is freshwater flow rate and *k* is a decay rate coefficient *(dC/dl = kC)*. Consider a tracer of concentration, discharged at *x=0* into an estuary. The solution for the tracer concentration from O'Connor (1960, 1965) is

At *<0:
Upstream of peak C=exp[Uf(1 +√U²f + 4Kd)x]
C₁ 2D U²f ....(5)
At *<0:
Downstream of peak C = exp[Uf(1 - √U²f + 4kD)x]
C1 2D U²f ....(6)
Lp stream of peak ,- = exp _ I 1 + J——2——

Where Uf = net downstream velocity from freshwater flow at x=0, where, the tracer concentration is C=Ci

At x=0

$$C_i = \frac{M}{Q\sqrt{(U^2 f + 4Kd)}/U^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

M = mass of non-conservative tracer/contaminant entering per time.

kg/s

Q = freshwater flow rate, m³/s

Values for the dispersion coefficient vary from 5 to 1000m²/s and Harleman (1964) suggested:

$D_l = 63n\, U_T R^{5/6}_H$ m²/s

Where, *n*= Manning's roughness coefficient

U_T=maximum tidal velocity, m/s

R_H = hydraulic radius, m

Results

The relative concentration of tracer upstream and downstream of the discharge point in an estuarine regime is studied.

It is noted that with the higher net downstream velocities, the upstream concentration is less but the downstream concentration is higher. This means that the higher velocities help to dilute the upstream concentrations and that they only transport but weakly dilute the downstream concentrations, examining the effect of two different dispersion rates, it is seen that the higher dispersion rate causes increased concentration upstream, but has little effect downstream of the Discharge point.

When wastes (with BOD strengths = *L)* are discharged to estuaries. They negatively impact on the dissolved oxygen levels. As such, the profile of DO will depend on the BOD loading. From O'Connor (1965), the one-dimensional, differential equations for steady flow are:

For BOD:

$$D_L \frac{d^2L}{Dx^2} - U_f \frac{dL}{dx} - kL = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots(8)$$

For DO:

$$D_L \frac{d^2D}{Dx^2} - U_f \frac{Dd}{dx} - K2D + kLx = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots(9)$$

Where, D = dissolved oxygen deficit, mg/L

L = BOD remaining, me mg/L

K = reaction coefficient, d^{-1}

K_2 = reaction coefficient, d^{-1}

Lx = BOD concentration at point x, mg/L

D_L = mixing dispersion coefficient

O'Cnnor's solutions are:

$$L = \frac{M}{Qm_1} \exp\left[\frac{U_f(1 \pm m_1)x}{2D_L}\right] \quad \ldots\ldots\ldots\ldots(10)$$

$$D = \frac{KM}{(K_2-k)Q} \left\{\frac{1}{m_1}\exp\left[\frac{U_f(1 \pm m_1)x}{2D_L}\right] - \frac{1}{m_2}\exp\left[\frac{U_f(1 \pm m_2)}{2D_L}\right]\right\}$$

Where, $m_1 = \left(\frac{U^2_f + 4KD_L}{U^2_f}\right)^{1/2}$ ....(11)

$m2 = \left(\frac{U^2_f + 4k2D_L}{U^2_f}\right)^{1/2}$

M = mass of BOD pollutant per time, kg/s

Conclusion

Systems Approach to Modelling of Water Quality in Estuaries have been analyzed the position sign in the exponent of the negative contaminants are available, but the solutions are numerical. The reader is referred to Tchobanoglous and Schroeder (1987), James (1993), Fischer *et al.* (1981) for more detailed treatment of estuaries water quality. Many programs exist for computer modeling of flow in estuaries including King (1990), Leenderste (1970) and Falconer (1991).

References

Lin B, Falconer RA. 1997. Tidal Flow and Transport Modelling using the ULTIMATE QUICKEST Scheme", J. Hydraulic Engineering ASCE. **123,** 303-314.

Kashefipour SM, Falconer RA. 1999. Numerical Modelling of Suspended Sediment Fluxes in Open Channel Flows", XXVII IAHR Congress, Graz, Austria.

Kashefipour SM, Lin B, Harris E, Falconer RA. 2000. Ribble Estuary Water Quality Modelling", Final Report, Cardiff University, UK, p. 454.

Fischer HB. 1979. Mixing in Inland coastal coaters. Academic Press New York.

O'Connor DE. 1960. Oxygen balance of estuaries J. Sanitary Energy Div. ASCE, Vol 86, SAE. p. 35.

O'Connor DJ. 1965. estuaries Distribution of non-conservative substances; E. Sanitary Energy. Div. ASCE 91 SAI. p. 25

Harierman DRE. 1914. the significance of hygiculum Dispersion in the Analysis of pollutants of estuaries Proc. 2nd Int. Conf on water solution neg. Tokyo Pergamon Press.

Tchobanoglous G, Schroedar ED. 1987. Water quality, Addison Wesley, Reading Massachusetts.

James A. 1993. An introduction to water quality modeling John Wiley, New York.

O'Rib GT. 1981. model for stratified impoundment in models for water quality management AK Biswas ed, Mc Graw Hill, New York.

King I. 1990. RMAA-A Two Dimensional Finite Element water quality models Dept. of Civil Engineering University of California at Davis March.

Leenderste. 1978. A water quality simulation model for well mixed estuaries and coastal seas Vol 1 to a Rand corporation Santa Monica California.

Falconer RA. 1991. Review of modeling flow and pollutant transport prowess in hydraulic basins: proceeding of water prediction L.C.W L.C roebel and CA. Brebbia Southanpton.