Studying waste load dispersion in Songkhla Lake using a simulation model

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Abstract Songkhla Lake is a large lagoon-like estuarine lake in southern Thailand which has been increasingly polluted in recent years by industrial and urban wastewater draining into the lake through various canals. This study was undertaken to construct a model of the dispersion of the pollution in the lake around the mouths of these canals in order to aid in the planning of effective pollution abatement measures. Results show pollutants dispersing up to 2 km in the sea during high tide, while at low tide, pollutants stay longer in the lake before being discharged into the Gulf of Thailand.

Key words waste load dispersion; Songkhla Lake Thailand; simulation model

INTRODUCTION

Songkhla Lake Basin is a significant natural resource in Thailand (Fig. 1). During the last several decades of population increase, which has required more land for farming and urban-industrial development, there has been a significant decline in the amount and quality of natural water resources in this area – as, indeed, across the entire country. In Songkhla Lake, this has led to shallowing of the lake due to the higher annual sediment loads; increased intrusion of saline water to the inner, normally mostly freshwater, part of the lake; a shortage of freshwater in the dry season (March–May) in some areas; and a reduction of some species of aquatic life. These problems must be addressed if Thailand is not to permanently lose this valuable natural water resource.

OBJECTIVES OF THE STUDY

To properly design mitigation measures for Songkhla Lake, it is necessary to understand the pollution impacts and their extent. This study was designed to construct a dispersion model to understand how the pollution in the wastewater in Songkhla Lake circulates, where it is dispersed to and how long it is retained in the lake, which will then lead to realistic ideas about how to solve the pollution of the lake.

MATERIALS AND METHODS

Data were mainly obtained from sites nearby the U-Tapao Canal, which has a major influence on the lower Songkhla Lake as it drains from Hat Yai city, the largest city in southern Thailand (Fig. 1, Table 1). Physical characteristics of the lake such as the tidal movement, wave movement, wind speed and inflow discharge from the surrounding land were studied along with major waste load parameters such as the Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), salinity, coliform bacteria and suspended sediment, all required to construct an accurate simulation of the concentration of the waste load in the lake.

PHYSICAL DESCRIPTION OF THE STUDY AREA

Songkhla Lake basin

Songkhla Lake basin is situated on the east coast of southern Thailand. It has a total area of 9807 km^2, of which 1046.04 km^2 is water and 8761 km^2 land (Fig. 1) (Sae-chew *et al.*, 1995). The climate is equatorial monsoon with a humid, hot rainy season. The mean temperature is 26.9ºC, the annual average precipitation 1800 mm and average evaporation 139 mm. The lake is surrounded by coastal plain, becoming rolling hills and finally mountains to the west and south. The plain and

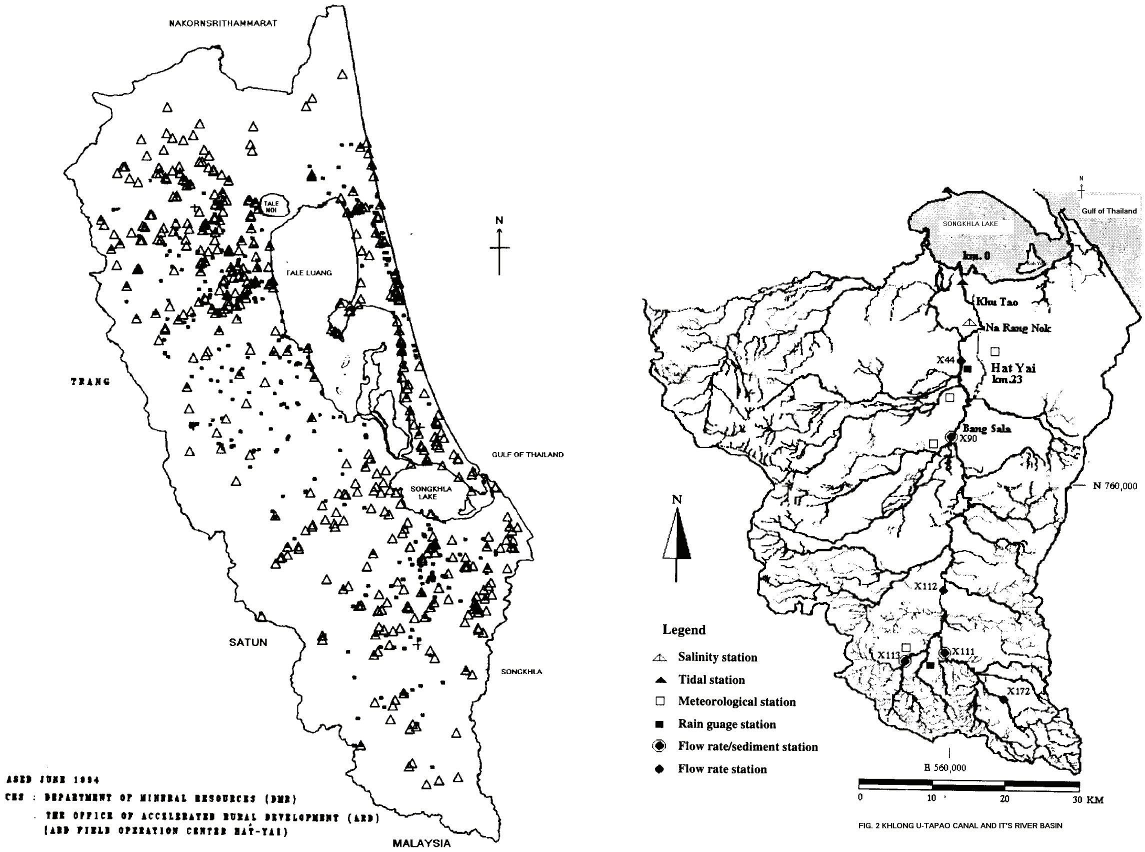

Fig. 1 Songkhla Lake and the river basin.

Table 1 Sediment station and mean annual sediment load.

River and station	Location	Drainage area (km^2)	Mean annual suspended sediments (tons) (year of record)
Khlong U-Tapao, Ban Bangsala	Hatyai, X90	1562	5458 (1978–1985)
Khlong Sadao, Ban Phrai	Sadao, X11	256	7218 (1979–1985)
Khlong Lam, Ban Thungprap	Sadao, X113	129	5689 (1979–1985)
Khlong Wat, Tonngachang	Hatyai ,NEA	14	2158 (1980–1984)

coastal areas are primarily used for agriculture and habitation, and the lake and surrounding ocean have always been a bountiful fishery.

The major canals draining into Songkhla Lake

U-Tapao Canal The U-Tapao Canal has a catchment area of 2305 km^2. The soil of the catchment is generally sandy and most of the area is covered with rubber plantations. The topography varies from a mild mountainous plateau on the west to the flat fluvial coastal landscape bordering Songkhla Lake on the east. The U-Tapao River basin gives a water yield to the catchment of 791.94×10^6 m^3 (1967–1986) and the U-Tapao canal has a discharge of 7.80 m^3 s^{-1} in the dry season (March–May) and 88.60 m^3 s^{-1} in the wet season (September–November). The width of the water surface varies 40–80 m and the depth of the canal 3.0–8.0 m. The distance from the upper regions to the mouth of the canal is about 70 km, with varying channel slopes.

Khlong Pavong There is a considerable fishery industry in this area, but most people are poor, with the overall result that a lot of municipal and industrial wastewater is released into the lake with insufficient water treatment via this canal which enters to the south of Koh Yo Island.

Khlong Sam Rong Around 6000 people live along this canal (Brans *et al.*, 1995) and contribute a significant amount of polluted water to the lake, which is also thought to have contributed to the demise of fish farming in the area neighbouring the lake in 1989 (R&D, 1989).

The process of waste load dispersion in Songkhla lake

The waste load dispersion process depends on the influences of tidal fluctuation, wind speed and direction, the density of the suspended load, the temperature difference of the water, turbulence of the flow, etc. Some additional parameters such as streamflow and flocculation were also considered in this study.

EQUATIONS OF THE MATHEMATICAL MODEL

A two-dimensional hydrodynamics simulation model (Swanson, 1986) was constructed by considering the equations of shallow water waves and the approximation method of Boussinesq. Curvilinear coordinate applications were adapted into the continuity and momentum equations. The conceptual calculation by the numerical solution method was applied by using a staggered grid (Lax-Wendroff explicit finite difference scheme), semi-different approximation and convective-diffusion of mass.

Continuity equation

$$\frac{\partial\zeta}{\partial\tau}+\frac{1}{r\cos\theta}\frac{\partial UH}{\partial\phi}+\frac{1}{r}\frac{\partial VH}{\partial\theta}-\frac{VH\tan\theta}{r}=0$$

Momentum equation of ϕ

$$\frac{\partial UH}{\partial\tau}+\frac{1}{r\ \cos}\frac{\partial UUH}{\theta\partial\phi}+\frac{1}{r}\frac{\partial UVH}{\partial\theta}-\frac{UVH\tan\theta}{r}=-\frac{1}{\rho_o r\cos\theta}\varphi\phi+\frac{\tau_b\phi}{\rho_o}$$

$$\varphi_\phi=\int_{-h}^{\zeta}\frac{\partial pdr}{\partial\phi}=\rho_o gH\frac{\partial(h+\zeta)}{\partial\phi}+\frac{gH^2}{2}\frac{\partial\rho'}{\partial\phi}$$

$$\tau_{b\phi}=\rho c_f U\ (U^2+V^2)$$

Momentum equation of θ

$$\frac{\partial VH}{\partial\tau}+\frac{1}{r\cos\theta}\frac{\partial UVH}{\partial\phi}+\frac{1}{r}\frac{\partial VVH}{\partial\theta}+\frac{U^2-V^2}{r}H\tan\theta=-\frac{1}{\rho_o r}\varphi\theta+\frac{\tau_b\theta}{\rho_o}$$

$$\varphi_\theta=\int_{-h}^{\zeta}\frac{\partial pdr}{\partial\theta}=\rho_o gH\frac{\partial(-h+\zeta)}{\partial\theta}+\frac{gH^2}{2}\frac{\partial\rho'}{\partial\theta}$$

$$\tau_b\theta=\rho c_f\ v\ \ (U^2+V^2)$$

with U,V = depth-averaged velocities in ϕ- and θ- directions, respectively; ζ = water surface elevation; $\tau_{b\phi}$, $\tau_{b\theta}$ = bottom shear stress in ϕ- and θ- directions, respectively; H = depth (mean sea level, m.s.l.); and C_f = bottom friction coefficient.

2-D vertically averaged model of waste load

$$\frac{\partial c}{\partial t}+\frac{1}{r}\frac{U\partial c}{\partial\theta}+\frac{1}{r}\frac{V\partial c}{\partial\phi}=\frac{D_H}{r^2\cos^2\theta}(c_{\theta\theta}-c_{\theta\phi}+c_{\phi\phi})-D_H\tan\theta\frac{\partial c}{\partial\theta}+s$$

$$S=-K_1c$$

with c = concentration of mass; D_H = diffusion coefficient in ϕ- and θ- directions; S = source term; K_1 = decay rate = 0.3–04 day^{-1}

RUNNING THE HYDRODYNAMIC MODEL

With a Songkhla Lake grid area designated for the model, a suitable grid width (500–1000 m) and grid number (18 × 20) with a time step of six hours for an explicit finite difference scheme were selected. The actual mean depth of the lake in selected areas was input (maximum mean depth is about 9 m at the outflow of the lake into the Gulf of Thailand and at the middle of the lake about

Fig. 2 Water depth contours in Songkhla Lake.

1.5 m; Fig. 2), followed by the tidal fluctuation. The initial condition of the current velocity in the lake was assumed to be zero. The dry season discharges of the canals around the lake were input. The model was run in one-hour increments for 16 days to simulate flows to be compared with measured field data. The coefficient of roughness was adjusted to achieve the best fit, by iteration of the whole calibration process, until a suitable level of agreement was achieved.

RUNNING THE WASTE LOAD TRANSPORT MODEL

The waste load transport model was tested in association with the calibrated hydrodynamic model to simulate the waste load dispersion pattern. First the fluctuation data (i.e. tide level) was entered, and the initial condition of the current in the lake was set as stationary with a velocity of zero. The initial lake water concentration conditions were also set to be zero in order to consider only the concentration from the canal itself. One by one the concentration of the wastewater discharges from each canal that flows into the lake was entered in order to visualize the individual impact from each flow. Using a time step of one hour the model was tested for a 16-day period to observe for critical events.

RESULTS OF THE MODEL TESTS

The model shows that the concentration of the waste dispersion varies in accordance with the current of the flow in the lake. The field data collected during the dry season (Fig. 3) showed that the salinity varied between 25 and 31 part per thousand (ppt) at Koh Yo Island, lessening to 12–29 ppt at the junction of the lake and the Gulf of Thailand. A salinity layer separation appeared at a level of more than 3 m depth, causing partial mixture of the water. The water temperature averaged 28ºC. The temperature difference between the surface and the bottom of the lake was approximately 1ºC. The concentration of the suspended load was between 6 and 25 mg L^{-1}. The bed load sediment varied from mud in most areas to sandy deposits nearer the outlets of the lake. The BOD5 (untreated) was 2–7 mg L^{-1}. Coliform bacteria counts were between 2 and 31 Most Probable Number (MPN)/100 ml in the lake, but increased in the canals to over 2400 MPN/100 ml. The tidal difference was about 40 cm with a phase difference of 3.5 hours. Maximum tidal current was about 0.67 m s^{-1} in the north, reducing to 0.43 m s^{-1} in the southern part of the lake close to the junction with the U-Tapao canal. The roughness coefficient of the lake was about 0.0015 and the current velocity simulation was accurate within a maximum velocity of 0.77 m s^{-1} and minimum velocity of 0.08 m s^{-1}. The collision of water masses in the lake due to phase and elevation differences induced complicated vortexes at the middle and the east side of the lake, but in the west part of the lake the currents were much smoother. The waste load released from the Khlong U-Tapao canal tended to disperse radially up to 2 km from the mouth of the canal, where there was still a concentration of 10 mg L^{-1} (Fig. 4). The model showed that if there is a consecutive and continuous release of wastewater for more than 2–3 days the east side of the lake will be the first

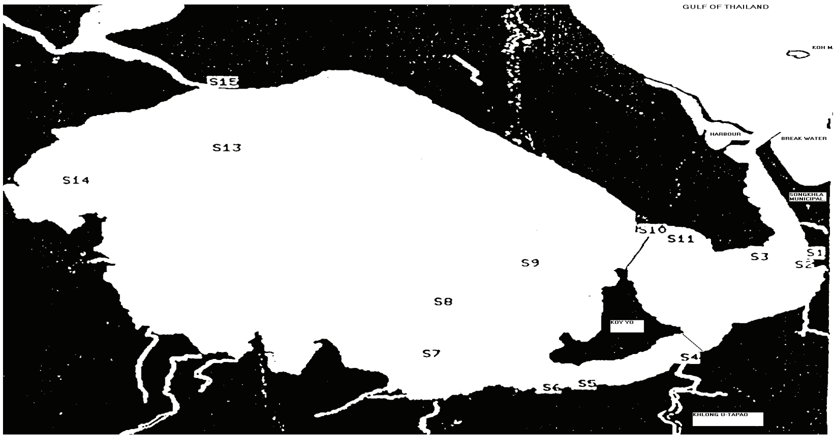

Fig. 3 Location of data collection points.

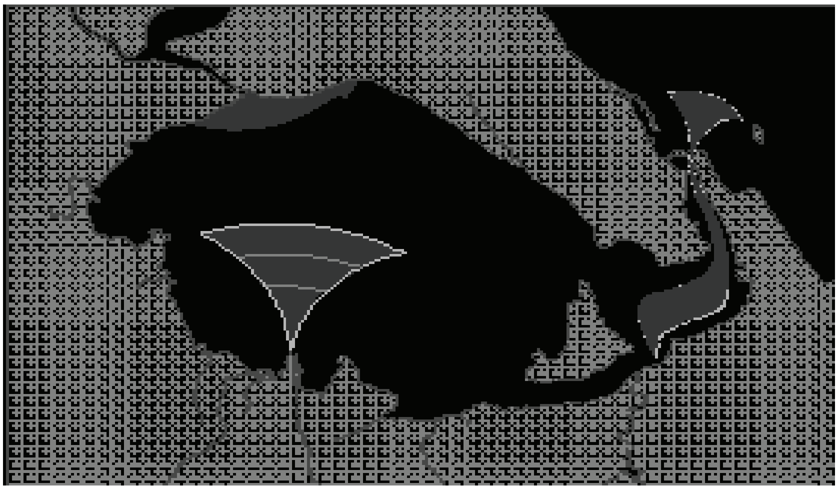

Fig. 4 Pattern of dispersed waste load in Songkhla Lake from U-Tapao Canal (lake is in black, land in grey and waste dispersion pattern in lighter grey).

place to be impacted seriously with a concentration of up to 50 mg L^{-1}, though minimal impact on the settled areas and fish farming areas of Koh Yo Island. However this area was seriously impacted from the waste dispersion of the Pavong Canal, which reaches out as far as 3 km from the mouth of the canal. The waste from Sam Rong Canal dispersed at the northern part of Koh Yo Island rapidly (Fig. 4), but still tended to accumulate within the lake as there was not enough time for it to be carried out to sea when there was a low tide.

CONCLUSION

The computer simulation model that was constructed to examine the dispersal of pollutants from the canals flowing in to Songkhla Lake accurately shows the dispersion patterns, and with it we can, in the future, predict the effect of decreased or increased pollutant loads from these sources, thus assisting in the development of suitable environmental regulations to reduce the pollution to acceptable levels in order to maintain the integrity of this valuable resource for Thailand.

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