# APPLICATION OF NUMERICAL MODEL ON THE WATER CIRCULATION AND SUSPENDED SOLID DISPERSION IN THE UPPER GULF OF THAILAND

## INTRODUCTION

Recently, numerical models have been widely developed to simulate some natural phenomena, such as dispersion of materials in water or air. Most of these models are based on physical laws governing these phenomena and utilize some mathematical techniques to solve the formulated equations. These models are very useful in analyzing and simulating the phenomena.

In this study, a numerical model (POM, Princeton Ocean model) was used to simulate the hydrodynamic circulation in the Upper Gulf of Thailand. The model was based on conservation of mass, momentum equations and was driven by tide. By using finite difference technique, simulation of total suspended solid concentration was performed. Total suspended solid (TSS) had received a great deal of attention. In order to understand the effect of sedimentation in details, it was indispensable to know the distribution patterns.

In an attempt to study on distribution patterns of TSS, several mathematical models had been formulated. The model consisted of set of mathematical expressions which were developed to represent the dispersion pattern of total suspended solid in the seawater. The conservation of mass was the basic principle of these models. The formulated equations together with some appropriate boundary and initial conditions were solved to obtain the spatial and temporal distributions of the studied water parameters. The results of the model were calibrated with LANDSAT image data. The results obtained from the models would display the distribution patterns of TSS concentration which were useful in managing located along the coastline and river banks.

# OBJECTIVES

1. Study the diffusion coefficient for seawater in the Upper Gulf of Thailand
2. Study the tide in the Upper Gulf of Thailand.
3. Simulate numerical model of tidal current in the Upper Gulf of Thailand
4. Simulate numerical model of suspended solid dispersion in the Upper Gulf of Thailand

# LITERATURE REVIEW

## 1. Topography

The Upper Gulf of Thailand is bounded by latitude 12° 40’N - 13° 30’N and longitude 100° E - 101° E (U.T.M. 1400000-1500000 N and U.T.M. 600000-710000 E). The Gulf was surrounded by the provinces of Phetchaburi, Samut Songkhram, Samut Sakhon, Bangkok, Samut Prakan, Chachoengsao and Chon Buri in the western, northern and eastern sides respectively, and is open to the Gulf of Thailand via the southern border. It has an area of 100x100 km$^2$ with the maximum depth of 40 m near Ko Khram. This area experiences mixed tides with 2-3 m tidal ranges.

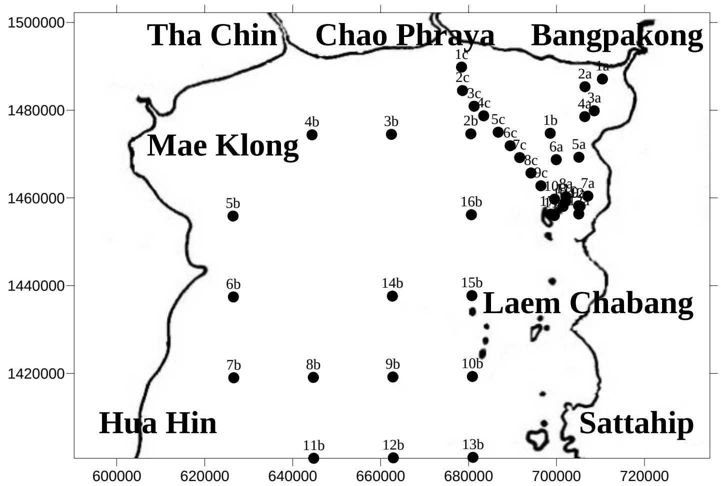


**Figure 1** Study site and sampling stations

Four main rivers (Mae Klong River, Tha Chin River, Chao Phraya River and Bang Pakong River) enter into the bay in the northern part as shown in Figure 1. For the whole year, each river discharges fresh water with high sediment load. Most of suspended solid load from rivers was mixed with seawater in delta and near shore areas.

**2. Eddy diffusion coefficient**

The diffusion of pollutants in the Upper Gulf of Thailand is governed by the tidal current which will convect the pollutant back and forth while the turbulence generated by tide, wave and other flows will diffuse or spread the polluting substance in all directions. Therefore, the eddy diffusion coefficient is very important parameter for pollution analysis.

Taylor (1921) hypothesis for expressing diffusivity in terms of Lagrangian statistics was used as basis for this study. Taylor showed that eddy diffusion coefficient, $\varepsilon$ (cm$^2$/sec.) of substances could be expressed as product of mean square of the fluctuation velocity ( $\nu'$ ) and Lagrangian integral time scale of large diffusion time.

$$\varepsilon = \overline{\nu'^2} \int_0^\infty R_L(\tau)\, d\tau \qquad (1)$$

where $\tau$ = dummy lag time variable

$R_L(\tau)$ = Lagrangian correlation coefficient

$\int_0^\infty R_L(\tau)\, d\tau$ = Lagrangian integral time scale

Since Lagrangian intergral time scale in case of fluid is very complicated to determine. In this study, the Eulerian integral time scale was used to estimate eddy diffusion coefficient which relation were investigated by Hay and Pasquill(1959). The relation might be expressed as:

$$\varepsilon = \overline{u'^2}\, \beta \int_0^\infty R_E(\tau)\, d\tau \qquad (2)$$

where $\overline{u'^2}$ = intensity of turbulence in x component

| | | |
|---|---|---|
| $R_E(\tau)$ | = | Eulerian correlation coefficient |
| $\int_0^\infty R_E(\tau)\,d\tau$ | = | Eulerian integral time scale |
| $\beta$ | = | ratio of Lagrangian to Eulerian integral time scale. |

Sasaki and Inoue (1984)' s observations expressed $\beta$ as:

$$\beta \cong 0.8\left(\frac{U_E}{\sqrt{\overline{u'^2}}}\right) \tag{3}$$

Narasimhan (1996) also presented the diffusion coefficients as:

$$\varepsilon = \overline{u'^2}\,\beta\int_0^\infty R_E(\tau)\,d\tau \tag{4}$$

Boonchum (2005) estimated the horizontal diffusion coefficient from how fast the dissolved or suspended substances dispersed in the water. He tried to delineate diffusion from the dispersion processes using the ratio of the turbulent scale and size of group of buoy. He showed that the horizontal diffusion coefficient could be written as:

$$\varepsilon = \frac{1}{4}\,\frac{\sigma_{t+1}^2 - \sigma_{t-1}^2}{2\,\Delta t} \tag{5}$$

where $\sigma$ = variance of buoy groups distribution in x and y component.

$t$ = time

**3. Tide**

Tide is produced by the attraction of sun and moon on the seawater. Due to these phenomena the regular rise and fall of water within a range of several meters are observed. Dronkers (1964) used the previous studies based on the sum of the periodic terms, so called tidal constituents developed a method to analyze the tidal observations for theoretical and practical purpose. The method is call harmonic analysis. The tidal constituents name, angular frequency and orbit relation could be expressed as Table 1.

At any time t, resultant tide can be expressed as follow;

$$Y = A_o + \sum_{n=1}^{\infty} H_n \cos(\omega_n t - \kappa_n) \tag{6}$$

where
- $Y$ = water level (m)
- $A_o$ = mean seawater level (m)
- $H$ = amplitude (m)
- $\omega$ = angular frequency
- $t$ = time (hr)
- $\kappa$ = phase lag
- $n$ = ordering number

(time in equation (6) on 1st January 2005 at 0:00 AM. for sea level computation was 920448.)

**Table 1** Constituents of tide and orbit relation

| Name of constituent | Symbol | Angular frequency (ω,°/hr) | Orbit relation |
|---|---|---|---|
| Solar annual | $S_a$ | 0.0410686 | Sun |

**Table 1** (Continued)

| Name of constituent | Symbol | Angular frequency ($\omega$,°/hr) | Orbit relation |
|---|---|---|---|
| Solar semiannual | $S_{sa}$ | 0.0821373 | Sun |
| Lunar monthly | $M_m$ | 0.5443747 | Moon |
| Lunisolar synodic fortnightly | $M_{sf}$ | 1.0158958 | Moon |
| Lunisolar fortnightly | $M_f$ | 1.0980331 | Moon |
| Larger lunar elliptic diurnal | $Q_1$ | 13.3986609 | Moon |
| Lunar diurnal | $O_1$ | 13.9430356 | Moon |
| Smaller lunar elliptic diurnal | $M_1$ | 14.496694 | Moon |
| Solar diurnal | $P_1$ | 14.9589314 | Sun |
| Solar diurnal | $S_1$ | 15.0000000 | Sun |
| Lunar diurnal | $K_1$ | 15.0410686 | Moon, Sun |
| Lunar | $OO_1$ | 16.1391017 | Moon |
| Lunar elliptical semidiurnal second-order | $2N_2$ | 27.8953548 | Moon |
| Variational | $\mu_2$ | 27.9682084 | Moon |
| Larger lunar elliptic semidiurnal | $N_2$ | 28.4397295 | Moon |
| Larger lunar evectional | $\nu_2$ | 28.5125831 | Moon |
| Principal lunar semidiurnal | $M_2$ | 28.9841042 | Moon |
| Smaller lunar evectional constituent | $\lambda_2$ | 29.4556253 | Moon |
| Smaller lunar elliptic semidiurnal | $L_2$ | 29.5284789 | Moon |
| Larger solar elliptic | $T_2$ | 29.9589333 | Sun |
| Principal lunar semidiurnal | $S_2$ | 30.0000000 | Moon, Sun |
| Lunisolar semidiurnal | $K_2$ | 30.0821373 | Moon, Sun |
| Lunar terdiurnal | $M_3$ | 43.4761563 | Sun |
| Shallow water overtides of principle lunar | $M_4$ | 57.9682084 | Sun |
| Shallow water overtides of principle lunar | $M_6$ | 86.9523127 | Sun |

Charuskumchornkul (1988) presented that in year 1982-1983, the classification of tide in the Upper Gulf of Thailand was defined as the mixed tide with the ratio of amplitude of $K_1$+$O_1$ and $S_2$+$M_2$ less than 3.0. By determining the sequences of each tidal constituent, it was found that the predominant constituents in the Gulf were the ones with periods of about a half day ($M_2$) and one day ($K_1$). He considered upon the fact that tidal length was very large compared with the dimensions of the Gulf; they were only a small fraction of tidal length.

Chokechalermwat (1990) showed that the mainly constituents of tide in the Gulf of Thailand were $M_2$, $S_2$, $O_1$ and $K_1$. Tidal range increased as the tide propagate from the mouth of the Gulf toward the end of the Gulf. Time lag of high water and low water in the Gulf was less than 2 hours.

Yanagi and Takao (1998) showed that phase of semidiurnal tides ($M_2$ and $S_2$) propagated clockwise in the central part of the Gulf of Thailand, although that of the diurnal tides ($K_1$, $O_1$ and $P_1$) was counterclockwise. The natural oscillation period of the whole Gulf of Thailand was near the semidiurnal period and the direction of its phase propagation was clockwise, mainly due to the propagation direction of the large amplitude part of the incoming semidiurnal tidal wave from the South China Sea.

Oonpan (2003) reported that tide significantly affected the circulation pattern in the Upper Gulf of Thailand. The effect of tide on current was studied by forcing the model with four major harmonic constituents which were $M_2$, $S_2$, $O_1$ and $K_1$. Sea level rose from the western part of the Gulf to the eastern part when the model was forced by $M_2$ and $S_2$. And sea level rose from the eastern part to the western part when the model was forced by $O_1$ and $K_1$.

Nutamashote (2003) showed that POM could precisely simulate the amplitudes and phases of those 4 diurnal tides at those 8 tide gauge stations but POM could poorly simulated amplitudes of phases of those 4 semidiurnal components. Comparison of simulated tidal currents with the measured ones at 2 oceanographic observation buoys in the Gulf of Thailand showed that POM favored diurnal tide while the actual tide were mixed.

Anongponyoskun (2004) showed tidal period in the inner part of Thailand was about 12 hours 25 minutes. The topography and physical of sea bed were affected by period of tide. In January, during spring tide, the lower low tide would be at nighttime. In May and September, during spring tide, the lower low water would be at daytime.

Anongponyoskun (2006) showed that main tidal constituents that could be used to predict sea level height as $M_2$, $S_2$, $K_1$ and $O_1$. In the entire area of the Upper Gulf of Thailand, phase lag and tidal amplitude of tide of each constituent did not differ much. The range of amplitude of tide is 1.5-3 m.

**4. Hydrodynamic model**

Dronkers (1964) dealt with some practical aspects of the use of tidal computations for rivers and coastal areas in one dimensional and two dimensional domains. Various aspects like dimensional computations for the transitional area of a river, used of explicit or implicit finite difference system, and the dimensions of grid and time step were discussed. Some important features of boundary conditions to determine the tidal movements from a practical stand point were discussed. A multi-operational method was developed by using a mixed explicit-implicit scheme. In this model, the time step was divided into two halves. In the first half, u' and h' were computed by means of an implicit method while v' was computed by an explicit method this method was found to be unconditionally stable.

Leendertse (1967) developed an alternating direction finite difference model for well mixed estuaries and coastal seas. He used staggered grids on which the velocities u and v and water level $\eta$ were computed recursively in each raw in the first half, in the second half the water level $\eta$ and velocity v were computed recursively in each column.

Kamphuis (1970) simulated a tidal river model such as St.Lawrence River using finite difference method. The implicit method had been chosen for this purpose because the scheme was unconditionally stable even though in the solution of the matrix no special pivoting was performed. He said that smoothing of discontinuities in detailed computations was seemed in the implicit scheme.

Weare (1976) analyzed the stability of two widely used finite difference schemes that were proposed by Leendertse. The analysis indicated the presence of a weak non linear stability, which was only controlled by the friction term under normal circumstances. The existence of the instability stemmed from the imperfect time-centering of the nonlinear terms. He concluded by saying that the only satisfactory way of avoiding this stability problem was used a fully time centered scheme.

Blumberg (1977) developed a plan view, two dimensional numerical models capable of predicting the tidal characteristics in Chesapeake Bay. In developing this model, the finite difference scheme was employed which saved a lot of computer time. The numerical simulation of the Chesapeake Bay demonstrated the presence of residual eddies and elucidates the tidal dynamics. He solved the hydrodynamic equations that governed the estuarine circulation patterns and salinity distributions by using an efficient numerical integration technique over an irregular estuary such as the Potomac River estuary and some dominant physical processes along with appropriate forms of the vertical turbulent mixing coefficients. An application to the Potomac River estuary produced simulations of velocity, salinity and tidal amplitude distributions, which were in agreement with observations.

Fuh (1977) developed a mathematical model to predict the tidal motion from the relationship between the harmonic constants of the tide and tidal currents. The tidal motion was firstly described, based on the Navier-Strokes equations of motion and the continuity equation. These equations were linearized to obtain a quasi-steady state solution for each tidal constituent by finite difference method with implicit and explicit shemes. The model was then applied to the Gulf of Thailand. The results were verified for the case of Sattahip Bay, Thailand.

Spaudling and Beauchamp (1983) studied the tidal circulations in some practical cases by using the two dimensional vertically averaged hydrodynamic equations developed by Leendertse's multioperational finite difference scheme. Comparison of predicted tidal range, high and low tidal phase lag and tidal currents to observed values had shown an excellent agreement.

Sojisuporn (1984) investigated computer simulation model of wind driven current in the Upper Gulf of Thailand. He showed that there was no horizontal circulation in the Upper Gulf which was related with wind driven current velocities.

Blumberg and Kantha (1985) formulated a shelf circulation model which incorporated an open boundary condition. Tidal ranges and phases calculated by the model were consistent with available observations.

Wang and Kreeke (1986) determined the tidal and wind-driven flow and circulation in the barrier island lagoon by using the nested numerical modeling approach. The nesting of one and two dimensional models provided an efficient solution model without scarifying predictive ability of resolution.

Sripunyawatchya (1988) showed that during the southwest monsoon, the surface current follows the wind direction into the Gulf of Thailand while the bottom current went in the opposite direction. During the northeast monsoon, the surface current flowed out of the Gulf while the bottom current flowed into the Gulf, the directions of surface current were slightly deviated from the direction of the wind.

Charuskumchornkul (1988) studied on hydrodynamic model in the Gulf of Thailand by using the particular selection parameters and boundary conditions. Alternating Direction implicit (ADI) finite difference scheme was developed to achieve the proposed problems. The calibration of the model to the current system was performed and showed the satisfactory comparison between the computed values and predicted values of tide level obtained by the harmonic analysis. Anyway, the results from this numerical model gave different circulation patterns. In the micro viewpoint, the contribution of river and shoreline boundary to the current field could predominate only in the neighborhood of coastline at some extents, whereas the open sea boundary, the assigned boundary values were the major factor controlling the simulated situation of computed values of current field. In addition to this, the effect of freshwater flow and the restriction of the coastline configuration were also affected to those computed values.

Phaksopa (2003) applied POM to simulate tidal circulation in Gulf of Thailand. The model grid space is 0.1 ° x 0.1° (11x11 $km^2$). The model was forced by eight tidal components ($M_2$, $K_1$, $O_1$, $S_2$, $Q_1$, $P_1$, $K_2$ and $N_2$) at the open boundary. The model results were verified using tidal data from 23 tide gauges in the Gulf. The results showed that the calculated values from POM correspond well with the observed ones.

Thudee (2005) showed that the tidal currents in the Upper Gulf of Thailand were influenced by the variation of tidal level which has the main harmonic constituent of M2. The result also showed that in the Gulf, the minimum tidal current velocity was around the mouth of Mae Klong River and maximum around the mouth of Bangpakong River. In the lower Gulf, the maximum tidal current was close to Sattahip in Chonburi Province.

**5. Water dispersion model**

Masch (1969) developed a finite difference transport mode for solving the convective dispersion equation in two dimensional well-mixed estuaries. The transport model was structured in such a way that it accepted basic input net velocities and depths from a two dimensional hydrodynamic model. The model described transport by convection and dispersion over long period of time for constant hydrologic inputs. The model was applied to Galveston Bay Complex along the Gulf coast of America.

Leendertse (1970) developed a two dimensional mass transport model by using alternating direction finite difference method. The space staggered scheme was used. In this model the mass transport equation was approximated by two finite difference equations. The time step was also separated into two halves. In the first half of the time step, one approximated equation was solved along the x direction, while in the second half, another equation was solved along the y direction. As an example, the model was applied to determine the distribution of coliforms in Jamaica Bay, Long Island, New York.

Siemons (1970) presented an ADI finite difference method to solve the two dimensional diffusion-advection equations with $v = 0$ by making use of the finite difference method developed for the one dimensional equation. The resulting system of linear equations was solved by means of elimination method.

Christodoulou *et al.* (1976) developed a numerical model for the quantitative description of the dispersion process in a two-layer system which represented an approximation for a natural water body during the summer season when a distinct thermocline existed. The model could handle any passive constituent, dissolved or suspended, possessing small vertical mobility and arbitrary decay characteristics, in a domain of irregular geometry and bottom topography. The formulation was based on the convection-diffusion equation, vertically integrated between the layer boundaries. The modeling of horizontal dispersion mechanisms and the relation of eddy diffusivity to the characteristic grid size and of shear dispersion to the local velocity profile were discussed.

Denelli and Tozzi (1977) implemented a three dimensional model to investigate a complex situation arising in estuarine seas or in large water bodies which were subjected to thermal stratifications and variable tidal effects. The assumption that vertical momentum equation could be reduced to the hydrostatic equation was excluded server upwellings and downwellings. The numerical method employed was based on partially implicit finite difference scheme to ensure adequate accuracy with reasonable computation time.

Holly and Usseglio (1984) developed and applied an accurate numerical method for the mathematical modeling of contaminant dispersion in two dimensional tidal currents. The characteristics method in conjunction with Hermite bicubic interpolation clearly solved the advection part of the dispersion equation with a minimum of numerical damping or oscillations. When coupled with a Crank-Nicholson finite difference solution of diffusion, the characteristic method formed a basis of a simulation algorithm which was straight forward, reasonable in computer memory and time requirements and capable of providing high accuracy solutions to the dispersion equation in two dimensional tidal flow.

Kovantanakul (1986) determined the usefulness of LANDSAT Multi Spectral Scanner (MSS) digital data for mapping surface suspended sediment in estuarine water of the Upper Gulf of Thailand, both in qualitative and quantitative analyses. The report showed that the shape and extent of sediment features flowing from the major rivers were much influenced by the season of river flow and tidal status. Their subsequent movement was affected by the prevailing winds. The largest sediment patterns were produced by the greater river flow in October-December and the sediment was transported south or southwest along the northern coastlines by the tidal current in ebb period and prevailing northeast monsoon winds. The sediment patterns were generated by the lower river flow persisting in the direction of south or southwest during the greater northeast monsoon winds in January, but in May such patterns tended to flow east in the first period of southwest monsoon winds.

Chieh (1987) presented a two dimensional model to describe thermal discharge in coastal regions. The model was integrated potential flow theory to calculate the ambient velocity field of the coastal water. The heat transport equation was solved for excess temperature calculation. The finite difference method for arbitrary boundary shapes was used to solve the stream function for current velocity calculation and the two-dimensional heat transport equation for the excess temperature calculation.

Ohgushi *et al*. (1989) developed a computational model for the calculation of non-linear advection term which combined the upwind difference and the six point scheme. This method yielded a very accurate solution for one dimensional Burger’s equation. The method was developed and computed nonlinear advection term with high accuracy and did not require solving cubic equations. This dealt with the pure advection of nonlinear case and also treated an example of calculating advection-diffusion. The application of this method to practical case was straight forward with few restrictions.

Anongponyoskun (1995) reported that solution of current computation was obtained on the basis of scheme of explicit method. The mathematical model was developed to predict the spread of dissolved Oxygen. The results of the prediction were nearly the same as the observation.

Narasimhan (1996) studied the variations of flow patterns and distribution patterns of some water quality parameters in the Upper Gulf of Thailand. Dispersion model was based on the vertically averaged substance balance equation. The depth averaged two dimensional mode was used to study the tidal circulation in a discrete representation of a continuum problem with a variety of computational procedures and boundary conditions which were currently available. By using ADI finite difference scheme, a combination of implicit and explicit schemes, the numerical model was developed to achieve the proposed solutions. The calibration of the results was performed and showed satisfactory comparison of observed and computed current speed and direction.

# MATERIALS AND METHODS

## Materials

### 1. Equipments

1.1 Sensor Data SD 6000 current meter

1.2 Sets of drogue

1.3 Computer and application software

1.4 Global water 15 WL Water Logger

1.5 Tide table for Thai water 2004, 2005

1.6 GPS

1.7 Map of the Gulf of Thailand 001 102 and 045

1.8 Satellite image in the Upper Gulf of Thailand provided by GISTDA

### 2. Data observation

The observed velocities of seawater every 10 minutes had been carried out by using Sensor Data SD 6000 current meter deploying below seawater surface 2 m at Ao Si Racha (707750E, 1458474N) in October 2004, May 2005 and September 2005 and near Ko Phai on 26$^{th}$ -27$^{th}$ January 2005 and Chao Phraya River mouth on 27$^{th}$ -28$^{th}$ January 2005. The set up of current mooring was shown in Figure 2.

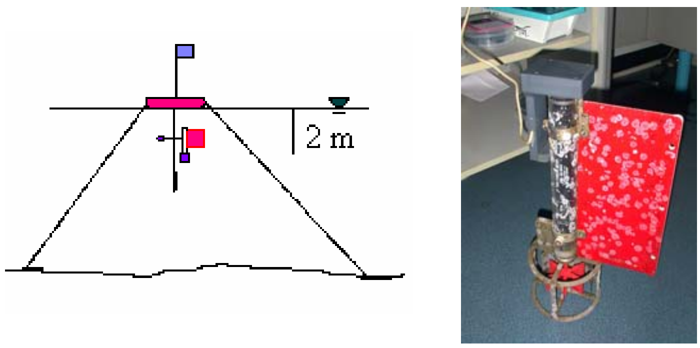


**Figure 2** A current mooring design used for observing tidal current

Hourly seawater level at Ao Si Racha (707750E, 1458474N) had been recorded by using Global water WL 15 Water Logger during 20th May -19th June 2005. Arbitrary mean sea level at the station was about 6 m above the sea bed. There are 2 tidal cycles per day. The period for each cycle is about 12 hours 25 minutes. The set-up for seawater level measurement was shown in Figure 3.

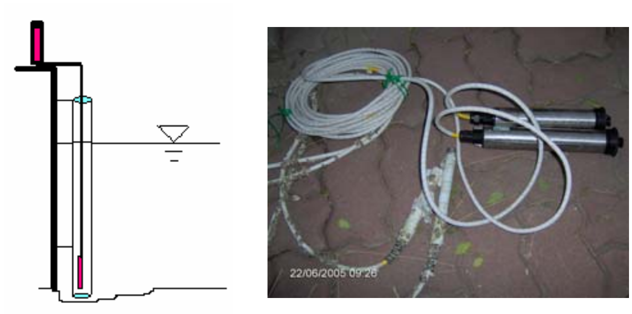

**Figure 3** Observing seawater level design by using Global water WL 15 Water Logger

The drogue design for the experiment was shown in Figure 4. Several buoys were deployed at each designated location. The drogues were deployed for 8 times on 18th, 26th -28th January, 15th -16th March, and 19th -20th May 2005. Six experiments were located along the coast at Ao Si Racha and Chao Phraya River mouth. And two experiments were carried out near Ko Phai.

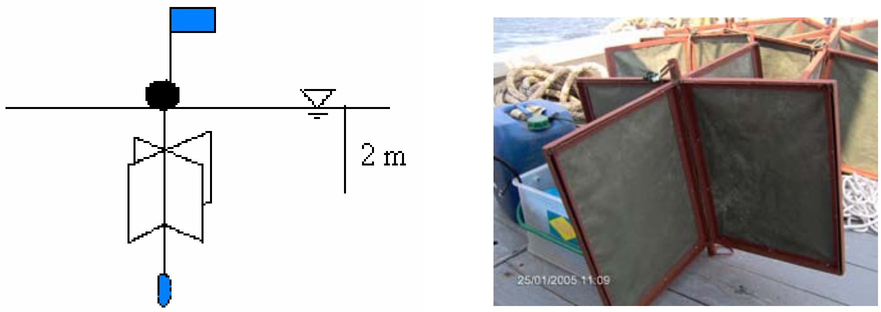


**Figure 4** A drogue design used for tracking flow behavior

**3. Sample analysis**

There was 10 cruises survey in the Upper Gulf of Thailand by Kasetsart 1. The Bangpakong River mouth-Si Chang Island had 6 cruises on 18th November 2004, 18th January 2005, 15th March 2005, 19th May 2005, 19th July 2005 and 23rd September 2005. There were 12 stations in each cruise. The 2 cruises with 17 stations around the upper Gulf of Thailand were performed on 8th October 2004 and 25th January 2005. The rest of the cruises, Chao Phraya-Si Chang Island with 12 stations, were operated on 10th January 2004 and 17th September 2005. Water samples were collected at every hour during 26th -28th January 2005, near Ko Phai and Chao Phraya River mouth for 25 hours. The seawater samples at the sea surface were filtered for the total suspended solid (TSS).

Total suspended solid were analyzed by the gravimetric method recommended by Strickland and Parsons (1965). That was weigh batch of 1.0 µm Glass Microfibre filters (GF/C 47 mm, Whatman) after washing with distilled water and heating for 2 hour at 450 C. Then each filter was place in the plastic box. By using vacuum filtration, a suitable volume of water sample depended on the turbid of water. To determine the total suspended solid, the filtered papers were dried and weighed. The difference weight of filter was divided by volume of water sample to give the TSS.

Water samples were collected for conventional laboratory testing of the TSS, which was correlated with the spectral reflectance from different bands. TSS coincide with the digital value were used to figure out which equation and which band was suitable for creating the simple chart of the TSS. Three bands of LANDSAT 5 TM and masking technique were used. A mask was hand-digitized from all 3 bands with natural color composite on the screen.

## Methods

**1. Hydrodynamic model (POM 2D)**

Study on Oceanographic in large area and surveys with limited data were very complicated. It was necessary to transform limited data to explain the nature phenomenal. Scientist developed the numerical simulation model for analyzing and prediction variation of nature by limited conditions.

One method of assessing the efficacy of planned or existing ocean outfalls is through utilization of mathematical models. Such models usually treat near and far field separately and differ mainly in that they include mass balance and momentum-flux terms in the near field eddy diffusion terms. In this study, POM (Princeton Ocean Model) which was written by standard Fortran 77 was used to develop hydrodynamic model.

The Horizontal finite difference scheme was Arakawa C grid. The horizontal grid is a curvilinear coordinate system; a rectilinear coordinated system might be easily implemented. The advection, horizontal diffusion, pressure gradient and Coriolis terms were contained in the governing equations. Horizontal grid was rectilinear, where dx was specified as a function of im and dy as a function of jm, or a more general orthogonal curvilinear grid in which case dx and dy were both function of im,jm.

1.1 Basic equations

The sigma coordinates equation which based on the transformation as

$$x^* = x\,,\; y^* = y\,,\; t^* = t \text{ and } \sigma = \frac{z-\eta}{H+\eta} \qquad (7)$$

The continuity equation was

$$\frac{\partial DU}{\partial x} + \frac{\partial DV}{\partial y} + \frac{\partial \omega}{\partial \sigma} + \frac{\partial \eta}{\partial t} = 0 \qquad (8)$$

The momentum equation were

$$\frac{\partial UD}{\partial t}+\frac{\partial U^2D}{\partial x}+\frac{\partial UVD}{\partial y}+\frac{\partial U\omega}{\partial \sigma}-fVD+gD\frac{\partial \eta}{\partial x}+\frac{gD^2}{\rho_0}\int_\sigma^0\left[\frac{\partial \rho'}{\partial x}-\frac{\sigma'}{D}\frac{\partial D}{\partial x}\frac{\partial \rho'}{\partial \sigma'}\right]d\sigma'=\frac{\partial}{\partial \sigma}\left[\frac{K_M}{D}\frac{\partial U}{\partial \sigma}\right]+F_x$$

$$\frac{\partial VD}{\partial t}+\frac{\partial UVD}{\partial x}+\frac{\partial V^2D}{\partial y}+\frac{\partial V\omega}{\partial \sigma}-fUD+gD\frac{\partial \eta}{\partial y}+\frac{gD^2}{\rho_0}\int_\sigma^0\left[\frac{\partial \rho'}{\partial y}-\frac{\sigma'}{D}\frac{\partial D}{\partial y}\frac{\partial \rho'}{\partial \sigma'}\right]d\sigma'=\frac{\partial}{\partial \sigma}\left[\frac{K_M}{D}\frac{\partial V}{\partial \sigma}\right]+F_y \tag{9}$$

Horizontal viscosity and diffusion term were defined according to

$$F_x \equiv \frac{\partial}{\partial x}\left(H\tau_{xx}\right)+\frac{\partial}{\partial y}\left(H\tau_{xy}\right)$$

$$F_y \equiv \frac{\partial}{\partial x}\left(H\tau_{xy}\right)+\frac{\partial}{\partial y}\left(H\tau_{yy}\right) \tag{10}$$

$$\tau_{xx} = 2A_M\frac{\partial U}{\partial x}$$

$$\tau_{xy} = \tau_{yx} = A_M\left(\frac{\partial U}{\partial y}+\frac{\partial V}{\partial x}\right) \tag{11}$$

$$\tau_{yy} = 2A_M\frac{\partial V}{\partial y}$$

The Smagorinsky diffusivity formula was

$$A_M = C\Delta x\Delta y\frac{1}{2}\left|\nabla V+(\nabla V)^T\right| \tag{12}$$

$$\left|\nabla V+(\nabla V)^T\right| = \sqrt{\left(\frac{\partial u}{\partial x}\right)^2+\frac{\left(\frac{\partial u}{\partial x}+\frac{\partial u}{\partial x}\right)^2}{2}+\left(\frac{\partial v}{\partial y}\right)^2} \tag{13}$$

1.2 Stability and convergence of model

The Courant-Friedrichs-Levy(CFL) computation stability condition on the vertically integrated, external mode, transport equations limits the time step according

$$\Delta t_E \leq \frac{1}{C_t}\left|\frac{1}{\delta x^2} + \frac{1}{\delta y^2}\right|^{-\frac{1}{2}} \quad (14)$$

where $C_t = 2(gH)^{\frac{1}{2}} + U_{max}$

$U_{max}$ = expected maximum velocity.

There were other restrictions but in practice the CFL limit was the most stringent. The model time step was usually 90% of this limit. The internal mode had a much less stringent time step since the fast moving external mode effects had been removed. The time step criteria was analogous to that for the external mode given by

$$\Delta t_I \leq \frac{1}{C_T}\left|\frac{1}{\delta x^2} + \frac{1}{\delta y^2}\right|^{-\frac{1}{2}} \quad (15)$$

where $C_T = 2C + U_{max}$

$C_T$ = maximum internal gravity wave speed based on the gravest mode, commonly of order 2m/s.

$U_{max}$ = maximum advective speed.

1.3 Condition of the hydrodynamic model

In this study, the developed POM which was simulated for the Upper Gulf of Thailand (1400000-1500000 N and 600000-710000 E) called large grid model and for Ao Si Racha (440000-1470000 N and 685000-710000 E) which was called small grid model. The models covered the area as shown in Figure 5. The models estimated seawater level, pattern of tidal current (magnitude and direction) at every grid point in the model. The models were reliable after the results were compared to the recorded data.

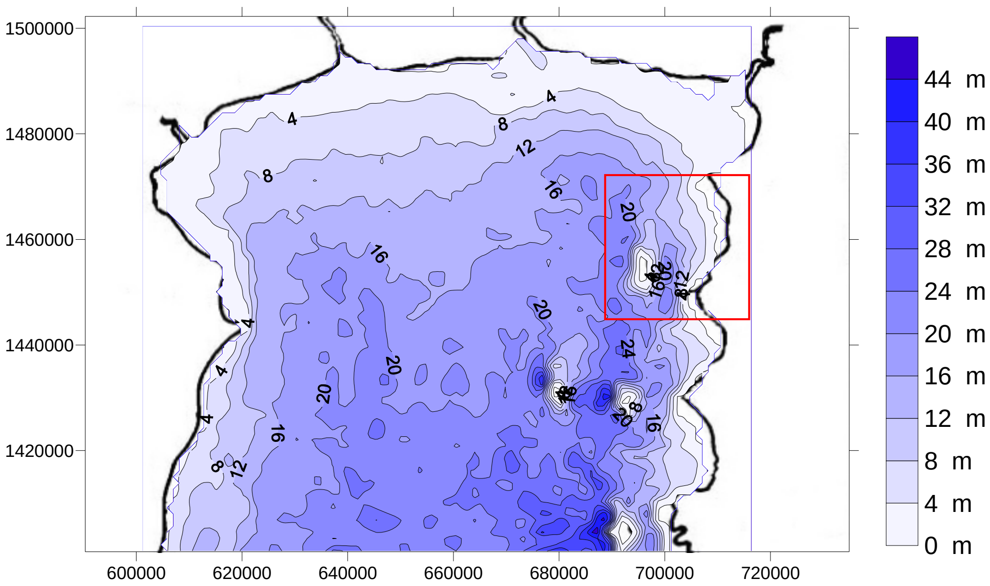


**Figure 5** Plot of the adjusted bathymetry

The initial values of tidal level and tidal current at the starting time of calculation were equaled zero over the entire area of large and small grid model. The boundary condition of the models, the interpolated sea level from harmonic equations at Hua-Hin and Sattahip were used to be south boundary of the models in large grid model and near Laem Chabang industrial estate in small grid model. The parameters which were used in large grid and small grid model were shown in Table 2. The flow chart of the hydrodynamic model could be shown in the figure 6.

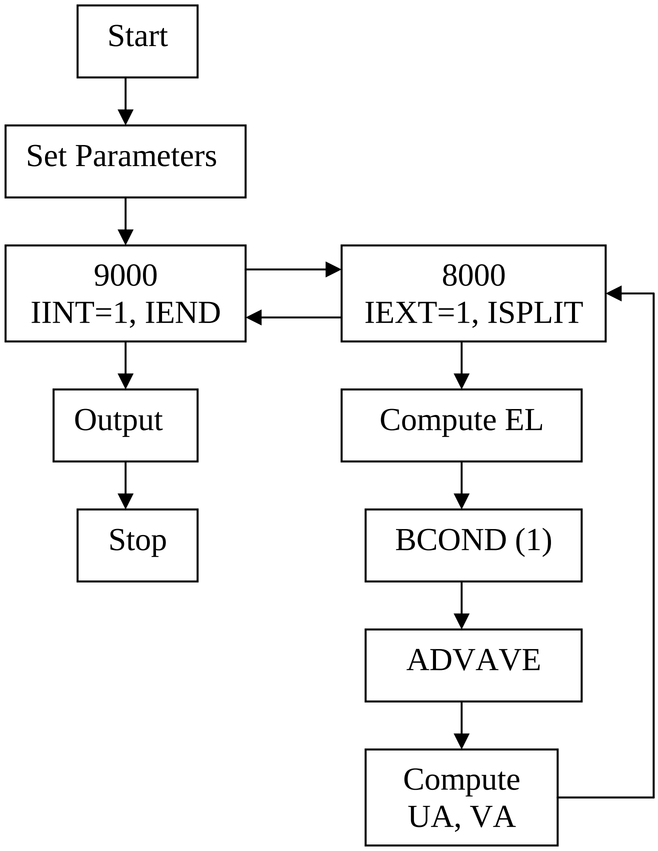


**Figure 6** Flow diagram of the Hydrodynamic model.

**Table 2** The parameters of POM model

| Parameter | Unit | Symbol | Large area | Small area |
|---|---|---|---|---|
| Study size | | im,jm | 65,55 | 26,34 |
| External mode time step | sec | $\Delta t_e$ | 6 | 6 |
| Internal mode time step | sec | $\Delta t_i$ | 180 | 180 |
| Grid size | m | dx,dy | 1860 | 930 |
| Smagorinsky diffusivity coefficient | | horcon | 0.2 | 0.2 |
| Von Karman constant | | $\kappa$ | 0.4 | 0.4 |
| Viscosity of seawater | $m^2s^{-1}$ | A | 50 | 10 |
| Density | $kg/m^3$ | $\rho$ | 1025 | 1025 |

## 2. TSS dispersion model

Knowledge on the seawater movement and the TSS runoff from the river mouth expected to provide the information on distribution of the TSS. In that aim a numerical model had been developed to predict the fate of sediments introduced to the marine environment from 4 rivers outflows.

TSS dispersion model described the transport and dispersion of sediments in the coastal environment. The model had been developed by well known 2 dimension differential equation of transport and diffusion of matter concentration.

### 2.1 Sources and sinks of TSS

The forces maintaining sediment in suspension are subject to continuous variations entailing corresponding variations in the quantity of the suspended sediment. If the force keeping sediment in suspension is reduced, the coarse particles gradually settle to the bottom, whereas if the suspending force is increased, larger fractions may be picked up than the bottom. Such changes are always gradual, starting with the finer particle sizes. Suspended sediment is characteristic mostly of flat river reaches. Over steep sections the reason for the usually smaller proportion of suspended sediment is the absence of fine sediment material rather than the insufficient magnitude of the suspending force. The active forces, their effect on the quality and quantity of sediment will be considered in detail in connection with the transportation of TSS.

The major sources and sinks of TSS in the Gulf depend on the deposition of the sediment and reentry of sediment into the water column. Averaged TSS and discharge of main rivers which were recorded by Harbor Department during year 1999-2000 were used as sources condition of the TSS dispersion model. The discharge of 4 main rivers and concentration of TSS were shown in Table 3.

**Table 3** Annual month recorded discharge ($m^3$/sec) and TSS (mg/l) in Maeklong River, Thachin River, Chao Phraya River and Bangpakong River

| | MaeKlong River | | Thachin River | | Chao Phraya River | | Bangpakong River | |
|---|---|---|---|---|---|---|---|---|
| | Q($m^3$/sec) | TSS(mg/l) | Q($m^3$/sec) | TSS(mg/l) | Q($m^3$/sec) | TSS(mg/l) | Q($m^3$/sec) | TSS(mg/l) |
| November | 491 | 1998 | 234 | 8714 | 1624 | 100 | 466 | 4734 |
| December | 192 | 5305 | 363 | 2377 | 1208 | 360 | 7 | 0 |
| January | 135 | 134 | 201 | 0 | 235 | 12 | 9 | 0 |
| February | 98 | 32 | 96 | 0 | 183 | 0 | 0 | 726 |
| March | 173 | 87 | 200 | 20 | 541 | 21 | 58 | 0 |
| April | 355 | 72 | 222 | 26 | 465 | 63 | 134 | 125 |
| May | 466 | 45 | 232 | 3 | 697 | 64 | 259 | 195 |
| June | 369 | 35 | 316 | 8 | 766 | 105 | 446 | 159 |
| July | 216 | 29 | 259 | 7 | 769 | 104 | 525 | 132 |
| August | 173 | 46 | 327 | 15 | 603 | 97 | 251 | 128 |
| September | 334 | 50 | 337 | 22 | 1058 | 99 | 487 | 87 |

2.2 Transport of suspended sediment

The water carrying suspended sediment concentration ($S_*$) is governed by the fall velocity incorporating both particle size and specific gravity and transported by flow of velocity V and depth h. Bogardi (1978) presents that the water carrying capacity for suspended sediment can be rewritten to be:

$$S_* = \eta_1 \frac{V^3}{h\,w} \qquad (16)$$

where $V = \sqrt{u^2 + v^2}$

$\eta_1$ was often assigned a practically constant value for particular water. From the results of sediment measurements made under saturation conditions on a number of rivers, Rossinsky and Kuzmin (1950) found $\eta_1 = 0.024$. Having examined the sediment transport relation suggested by several Soviet authors, Salakhov found that $\eta_1 = 0.0135$ which, in comparison with the value 0.024, implies that the sediment transported in alluvial streams is in general less than that pertaining to saturation concentration.

The boundary condition in sediment transport at which channel erosion was initialed had also been studied by Rossinsky (1970). In this condition which might be regarded as the critical, additional sediment was scoured from the channel owing to the excess energy flow. For this condition Rossinsky (1970) found $\eta_1$ = 0.0005.

## 2.3 Basic equations

In developing water quality models, the dispersion process and the interaction processes of the selected water quality parameters would be considered. The basic governing equation of the dispersion model was the substance balance equation which represents the principles of mass conservation. This equation included terms representing advective and dispersive transports as well as terms representing source and sink of the substance.

The vertically averaged form of the TSS balance equation could be written as

$$\frac{\partial S}{\partial t} + u\frac{\partial S}{\partial x} + v\frac{\partial S}{\partial y} = \frac{\partial}{\partial x}(K_x \frac{\partial S}{\partial x}) + \frac{\partial}{\partial y}(K_y \frac{\partial S}{\partial y}) - \alpha w(S - S_*) \qquad (17)$$

Where

| | | | |
|---|---|---|---|
| Where | $S$ | = | depth-averaged suspended-load concentration |
| | $K_x$, $K_y$ | = | diffusion coefficient of sediment in x and y component. |
| | u and v | = | velocities in x and y component. |
| | $\alpha$ | = | constant coefficient |
| | w | = | settling velocity (0.01 cm/sec) |
| | $S_*$ | = | water carrying capacity for suspended sediment |

## 2.4 Stability and convergence of model

The solutions of finite differential equation were not approximate in sense of crude estimates. Finite difference methods generally gave solutions that were either as accurate as data warrant or accurate as was necessary for technical purposes for which solution were required.

The effects of rivers, intakes could be included in a simulation. These source and sinks were included in TSS dispersion models. The discharges were specified in the basic parameters.

The time step for the TSS dispersion simulation was the same as the one used for hydrodynamic simulation, since the two models were fully coupled. Both the hydrodynamic model and the TSS dispersion model had to be considered, when selecting the time step. For stability and convergence of TSS dispersion model, Ueno (1967) assumes that

$$4\frac{\Delta t}{\Delta s}\left(\frac{U}{2}-\frac{K}{\Delta s}\right)<1 \qquad (18)$$

2.5 Successive over relaxation method (S.O.R.)

For solving large linear system of finite differential equation, it requires iterative method for convergent predicted values. The iterative procedure close to be convergent when the difference between the exact solution and the successive approximates tend to be zero as the number of iterations increase.

Because the dispersion problems are nonlinear, iterative methods are often used, especially for the solution of multimensional problems. The simplest iteration methods are Jacobi method and Gauss-Seidel method which are expressed by Smith (1974). However, the convergence speed of these two methods is usually slow. To speed up the convergence, S.O.R. iterative method is widely used.

In this study, S.O.R. was selected since it converges very fast; Ueno (1967) expressed equation of S.O.R. as:

$$^{\nu+1}S_{i,j}^{n+1} = {}^{\nu}S_{i,j}^{n+1} + \alpha_2 \, {}^{\nu}R_{i,j}^{n+1} \tag{19}$$

where $\alpha_2$ = acceleration parameter($1 < \alpha_2 < 2$)

$^{\nu}R_{i,j}^{n+1}$ = displacement or specified accuracy

$^{\nu}S_{i,j}^{n+1}$ = $\nu$ th iterated value

2.6 Condition of the TSS dispersion model

For the modeling in the large area as the whole Upper Gulf of Thailand, the river topography was usually considered very small compared with the grid size of the elements. River boundary was determined when the local effects of the river flow was taken into consideration. For a channel with a small cross-sectional area, the flow component and the lateral variation in the substance concentration were small. In this case the dispersion process could be considered to be one dimensional. For large water bodies such as the coastal sea, the flow components as well as the substance dispersion varied in all directions, and caused more rapid decline of the substance concentration at the discharge point.

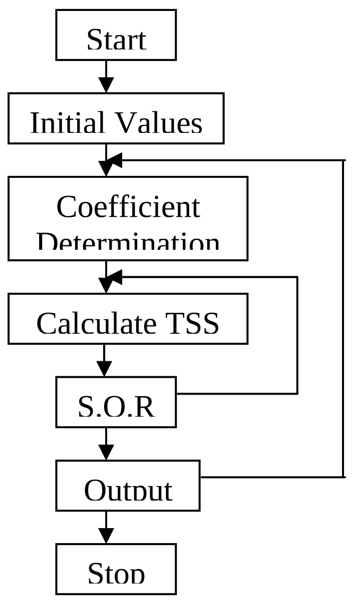


**Figure 7** Flow diagram of the TSS dispersion model.

In this study, we assumed that the discharge and TSS which related to tide were continually runoff into the Upper Gulf of Thailand from only 4 main rivers. The parameters which used in the model were shown in Table 4. The discharge and TSS concentration were considered in 2 steps that discharge was QH and QL while TSS was SH and SL, respectively. The flow chart of TSS dispersion model could be shown in Figure 7.

**Table 4** The parameters of TSS dispersion model

| Parameter | Unit | Symbol | Value |
|---|---|---|---|
| Study size | | im,jm | 65,55 |
| Time step of computing | sec | $dt_e$ | 600 |
| Time step of output | hr | $dt_i$ | 4 |
| Grid size | m | dx,dy | 1860 |
| Diffusivity coefficient of coastline | $m^2s^{-1}$ | K | 10 |
| Diffusivity coefficient of off shore | $m^2s^{-1}$ | K | 5 |
| Constant coefficient | | $\alpha$ | 0.01 |
| Practically constant | | $\eta_1$ | 0.0005 |
| Acceleration parameter | | $\alpha_2$ | 1.3 |
| Discharge | | | Wet Dry |
| - Mae Klong River | $m^3s^{-1}$ | $Q_H$, $Q_L$ | 400, 50 |
| - Tha Chin River | | | 400, 50 |
| - Chao Phraya River | | | 1000, 100 |
| - Bangpakong River | | | 400, 0 |
| Concentration of TSS | | | |
| - Mae Klong River | mg/l | $S_H$, $S_L$ | 50, 30 |
| - Tha Chin River | | | 30, 20 |
| - Chao Phraya River | | | 100, 50 |
| - Bangpakong River | | | 120, 50 |

**3. Satellite image data and field survey**

Remote sensing may be broadly defined as the collection of information about an object without being in physical contact with the object. The term remote sensing is restricted to methods that employ electromagnetic energy as the means of detecting and measuring target characteristics. Electromagnetic energy includes light, heat and radio waves. This definition of remote sensing excludes electrical, magnetic and gravity surveys that measure force fields, rather than electromagnetic radiation.

A number of interactions are possible when electromagnetic energy encounters matter, whether solid, liquid, or gas. The interactions that take place at the surface of a substance are called surface phenomena. Penetration of electromagnetic radiation beneath the surface of a substance results in interactions called volume phenomena. The surface and volume interactions with matter can produce a number of changes in the incident electromagnetic radiation. The science of remote sensing detects and records these changes. The resulting images and data are interpreted to identify remotely the characteristics of the matter that produced the changes in the recorded electromagnetic radiation.

The wavelength bands of the electromagnetic spectrum and radiometric characteristics of the TM Sensors were described in Table 5-6. Electromagnetic radiation in the different wavelength bands interacts differently with matter.

A lot of valuable information about suspended sediment distribution in an estuarine region can be gained from the imagery obtained from LANDSAT satellites. The remote sensing data (supported by Geo-Informatics and Space Technology Development Agency, GISTDA) was used in this study were the image LANDSAT 5 TM with the path/raw 129/51 and acquisition date of 5$^{th}$ December 2003, 20$^{th}$ October 2004, 21$^{st}$ November 2004, 8$^{th}$ January 2005, 13$^{th}$ March 2005 and 19$^{th}$ July 2005. The bands which were used to estimate the dispersion of TSS were band 1, 2, and 3.

**Table 5** Image Characteristics of LANDSAT 5

| Band number | Spectral range(microns) | EM Region | Generalized Application details |
|---|---|---|---|
| 1 | 0.45-0.52 | Visible Blue | Coastal water mapping, differentiation of vegetation from soils |
| 2 | 0.52-0.60 | Visible Green | Assessment of vegetation vigor |
| 3 | 0.63-0.69 | Visible Red | Chlorophyll absorption for vegetation differentiation |
| 4 | 0.76-0.90 | Near Infrared | Biomass surveys and delineation of water bodies |
| 5 | 1.55-1.75 | Middle infrared | Vegetation and soil moisture measurements; differentiation between snow and cloud |
| 6 | 10.40-12.50 | Thermal infrared | Thermal mapping, soil moisture studies and plant heat stress measurement |
| 7 | 2.08-2.35 | Middle infrared | Hydrothermal mapping |

**Table 6** Radiometric characteristics of the TM Sensors

| Property | LANDSAT 5 |
|---|---|
| Band1-5 & 7 | 30x30 m |
| Band 6 | 120x120 m |
| Swath width | 185 km |
| Repeat coverage interval | 16 days(233 orbits) |
| Altitude | 705 km |
| Quantization | 8 bits(256 levels) |
| On-board data storage | Magnetic tape failed |
| Orbit type | Sun-synchronous |
| Inclination | 98.2° |
| Equatorial crossing | Descending node:10:10am |