CHAPTER III

METHODOLOGY

The secondary data was used to study the seasonal and long-term variations and calculate nutrient budgets of the Upper Gulf of Thailand. Data from 1987 to 1994 was studied the seasonal and long-term variation of nutrients while data in 1989, 1990 and 1994 was chosen to establish the nutrient budget because the extensive hydrochemical observations in the bay was made by Department of Fishery coinciding with the intensified study of freshwater inputs (river runoff , precipitation and evaporation) and riverborne nutrient concentrations made by Royal Irrigation Department, Meteorological Department, Pollution Control Department and Department of Health. These information will be integrate in the Upper Gulf of Thailand database.

The Upper Gulf of Thailand database

Long-term variations of nutrients in the Upper Gulf of Thailand were proposed to use the secondary data for studying the seasonal and long-term variations and calculating the nutrient budgets. In order to achieve these objectives, the secondary data from the various sources in Thailand were documented and stored in a database. The Upper Gulf of Thailand database was accessed by Paradox version 4.50 for DOS.

The secondary data in the Upper Gulf of Thailand database consist of:

1. freshwater inputs during 1979-1994 (the Royal Irrigation Department)
2. riverborne nutrient concentrations during 1988-1992 (the Pollution Control Department and the Department of Health)
3. hydrochemical data during 1987-1994 (the Department of Fishery), hydrological data on March 1993 (Royal Thai Navy) and hydrological data from electronic buoys (Sea Watch Project)

4. meteorological data around the Upper Gulf of Thailand during 1978-1994 (the Meteorological Department)
5. bathymetical data on March 1993 (Royal Thai Navy)

The data structures of the Upper Gulf of Thailand database and the scripts for extracting or developing the database were described in Appendix A and B, respectively.

Hydrochemistry of the Upper Gulf of Thailand

Secondary data in 1989, 1990 and 1994 was chosen to establish the nutrient budget because the extensive hydrochemical observations in the Gulf were made (data was continuously collected covering the whole area of the Upper Gulf). Hydrochemical Observations were made at stations in the Upper Gulf of Thailand. These stations were part of fixed stations network routinely visited by research vessels from the Marine Fishery Division, Department of Fishery (Figure 3.1). These information were observed at three different depths (surface, mid-depth and bottom) except station no. 1-7, 9, 14-15, 20, 25-26 and 32. They were observed only at two different depths (surface and bottom) because they are locate in the shallow zone.

Freshwater inputs and riverborne nutrient inputs

The main freshwater inputs drains into the Upper Gulf of Thailand through the four major river along the northern boundary (Figure 3.2). Freshwater runoff were observed at upstream stations by the Hydrology Division, Royal Irrigation Department. Monthly freshwater runoff were calculated from daily runoff observations. Another source of freshwater inputs into the Upper Gulf is precipitation. The precipitation over the Upper Gulf was represented by the average rainfall from seven meteorological stations around the Gulf (pilot station at Samut Prakhan (to the North), Chon Buri, Ko Sichang (the island stations), Patthaya, Sattahip (to the East), Phetchaburi and Hua Hin (to the West). Data measured in term of length per time (mm/month).

The riverborne nutrient loads were directly estimated by multiplying of nutrient concentrations by freshwater runoff. Concentrations of nutrients were observed close

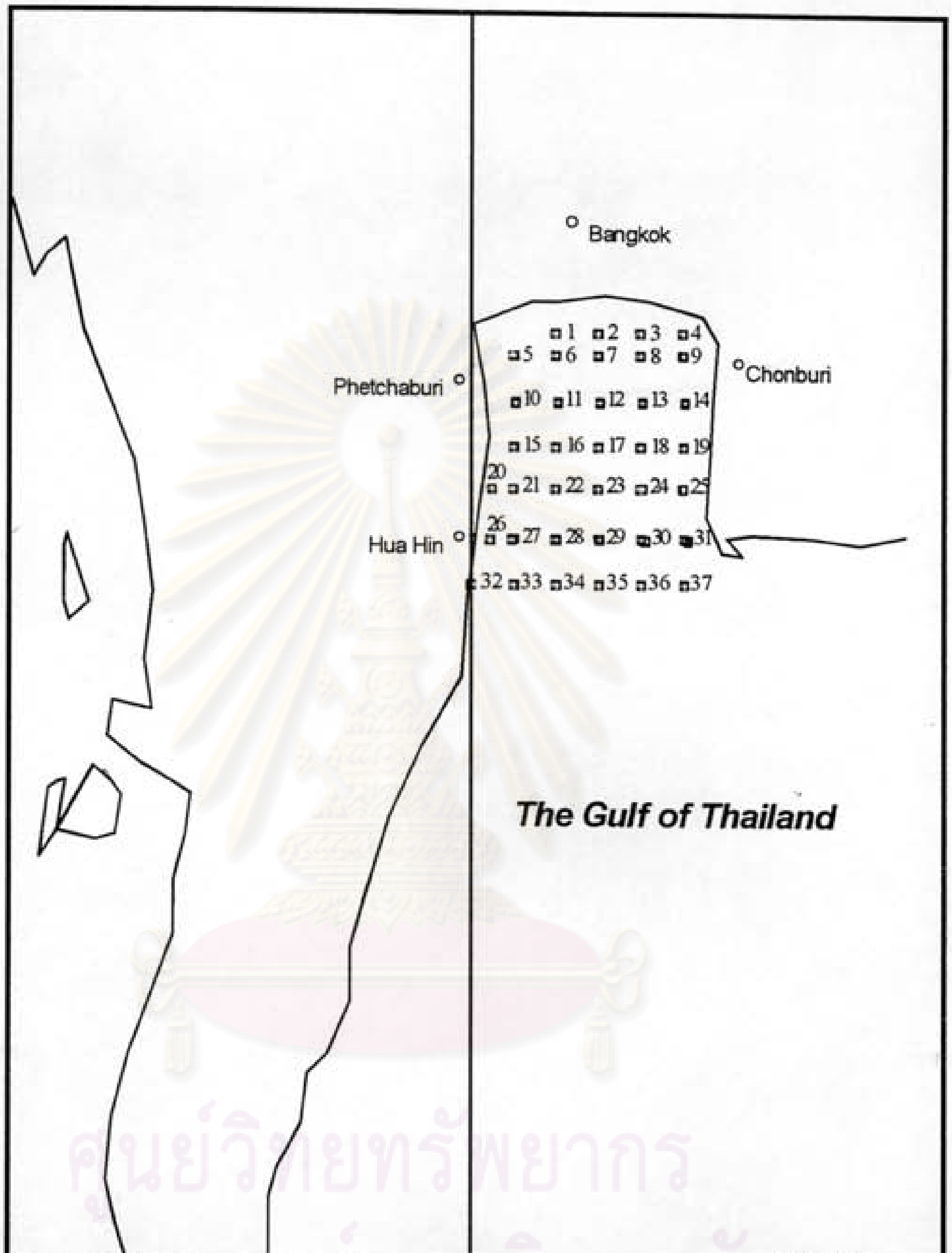

Figure 3.1 The fixed stations network of the Department of Fishery in the Upper Gulf of Thailand.

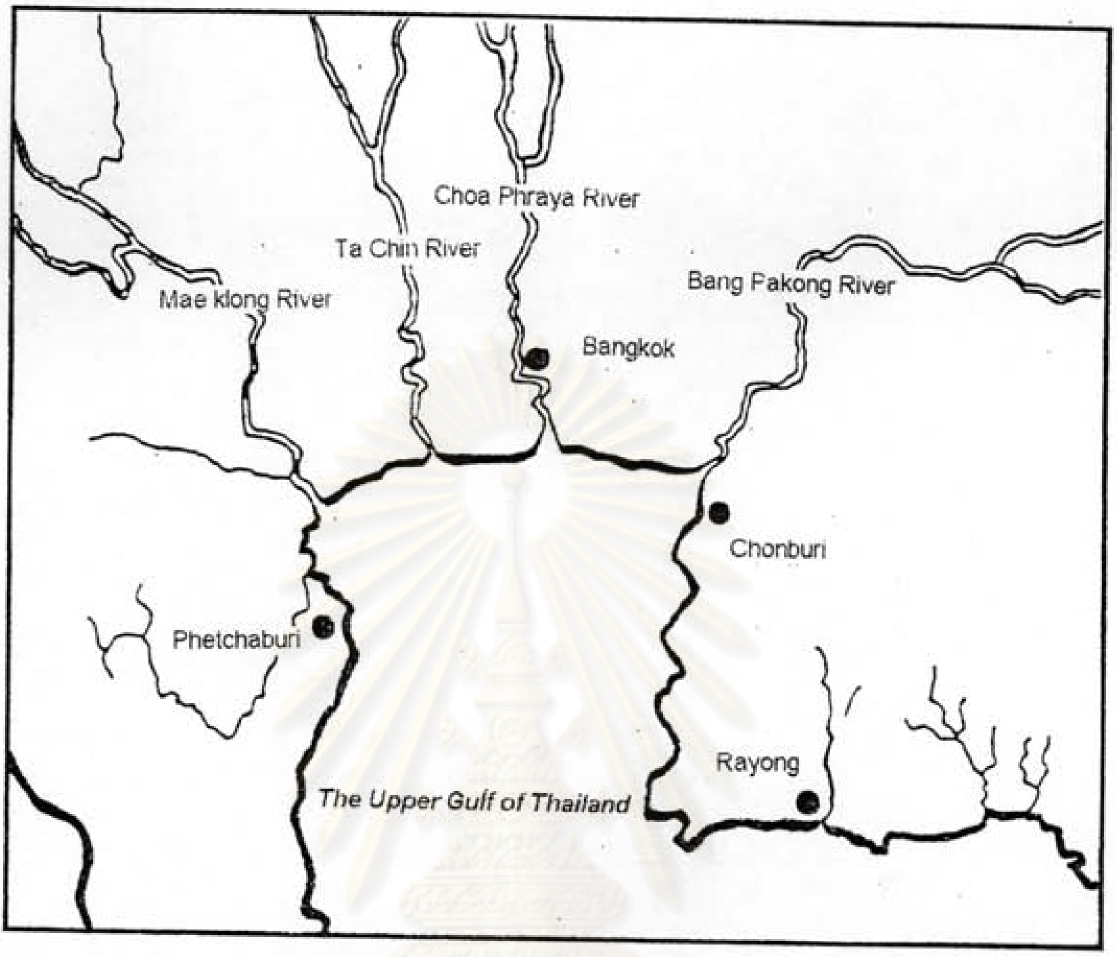

Figure 3.2 Four major rivers drained into the Upper Gulf of Thailand

to the rivermouths on three or four times per year by Freshwater Division, Pollution Control Department, while freshwater runoff is continuously measured (daily observed). Thus, the continuously riverborne nutrient concentrations are required to interpolate by estimating the relationship between concentration and runoff, as described in the next section. The concentration of nutrients in rainfall are likely to be small. Consequently, the airborne nutrient loads can be negligible.

Interpolation of riverborne nutrient concentrations

The approach is to plot the available concentration data as a function of river runoff, usually both as logarithms, and estimate the relationship between concentration and runoff (Thoman and Mueller, 1987). For each runoff (Q) then where the concentration was not measured, this relationship is used to estimate the concentration (c), and hence, the load. Thus, it is assumed in this method that:

$$c = aQ^b \tag{3.1}$$

where

$$b = \frac{\ln(c_1/c_2)}{\ln(Q_1/Q_2)} \tag{3.2}$$

and $$a = \frac{c_1}{Q_1^{\,b}} \tag{3.3}$$

Evaporation

Evaporation is the one of most important term which determined in the water budget (in order to establish the nutrient budget). This data has observed only four meteorological stations around the Upper Gulf (Hua Hin, Phetchaburi, Chonburi and Phattaya) by the Meteorological Department. Data is measured in term of length per time (mm/month).

Seasonal and long-term variations of nutrients in the Upper Gulf of Thailand

In order to achieve the better understandings of nutrients of the Upper Gulf of Thailand, descriptive of the distribution pattern, the possible seasonal and long-term variations were discuss. The graphical displays of nutrients were made for helping to interpret and discuss. The relational program to create the displays are Surfer Version 5.01 for Windows, Sacha Protected Mode Version for DOS and Microsoft Excel Version 5.0a. Contour and transect profile of nutrients in the Upper Gulf were ploted by using Surfer Version 5.01 for Windows and Sacha Protected Mode Version for DOS, while timeseries of nutients were ploted by using Microsoft Excel Version 5.0a. These displays were integrated in the category of the Upper Gulf of Thailand profiles.

Mathematical structure of nutrient budgeting procedure in the Upper Gulf of Thailand

This section focuses on the mathematical structure and formulation and the other aspects of model development for nutrient budgeting in the Upper Gulf are described.

General background

Water budget

Water budget was established and presented by the hydrochemical cycle concept. A simple box diagram illustrating the conceptual water budget for a coastal water body is shown in Figure 3.3. The fundamental concept of the budget is the water mass conservation. Therefore, the water volume change in the system with time may be represented by the balance between water inflows and outflows. Water inflows to the system include the volume fluxes of freshwater runoff, the direct fluxes of precipitation, the advective inflow and the others inflows such as groundwater and Water outflows from the system include evaporation and advective outflow (residual flow). Freshwater inflows and evaporative outflow are generally available by the direct measurement, while advective outflow is calculated to compensate the net water outflow (or inflow) in order to balance the water budget. In general, the residualflow will be negative (out of the system) in the systems where freshwater input dominates. In the most cases, other freshwater sources such as groundwater and sewage are likely to be small and can be ignored and it is reasonable to assume that the water volume remains constant.

Salt budget

In general, the coastal marine systems which water inflow and outflow are effected by tides, winds, and density there will be diffusion processes across the system boundaries in addition to the residual flow. These terms are not significant in water budget because they is likely to balance out over time. However, these flows cause a

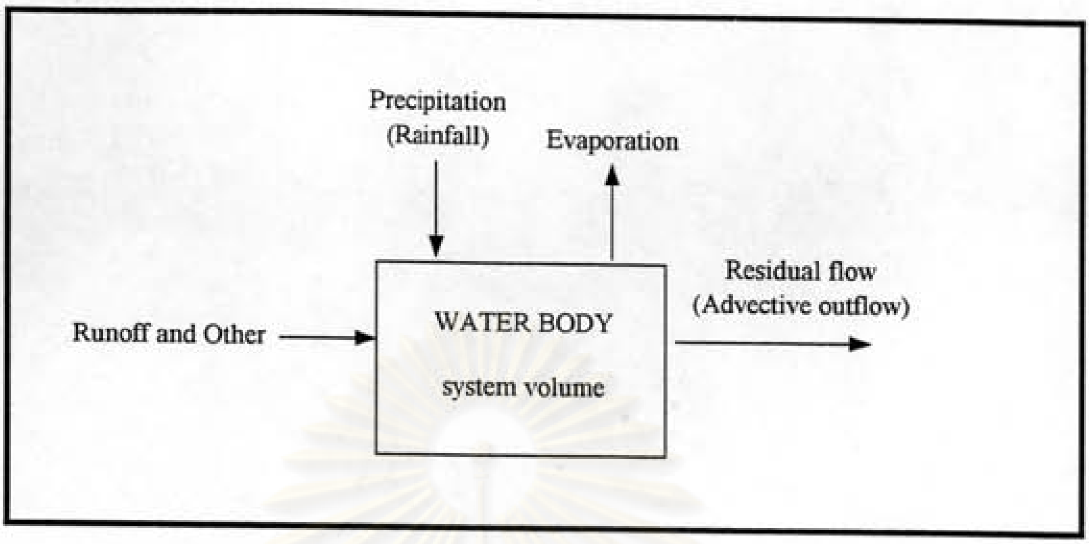

Figure 3.3 A simple box diagram of the water budget in the coastal water body.

material exchange between the interested and adjacent system and are important to construct into the material budgets. These exchange fluxes may often be considered in term of mixing. Salt budget based on salt flux balance within the system was established in order to evaluate the water flows and mixing because salt is not either produced or consumed in the system (that is the conservation of salt).Under such conditions, mixing is likely to transport salt in to the system. A simple box diagram illustrating the salt budget for a coastal water body is shown in Figure 3.4. Occasionally, salinity may be not truly conservative with respect to water because salt within the ocean system is changing by internal reactions including significant evaporite deposits. Ion ratios may vary extensively in low salinity system, so the entire concept of "salinity" becomes quantitative. In such systems, it is better to use the specific materials which is explicitly defined as non-reactive properties (for example, chloride). In most cases, salinity of streams or groundwater flowing into estuarine systems or the sight salt content of precipitation are likely to be small and can be ignored.

The exchange of water between the interested and adjacent systems is described as the processes of advection and mixing by the combined water and salt budgets. If there is no salinity different between the systems, or if water exchange pattern is too complex to be clearly described by the simple water and salt budgets,

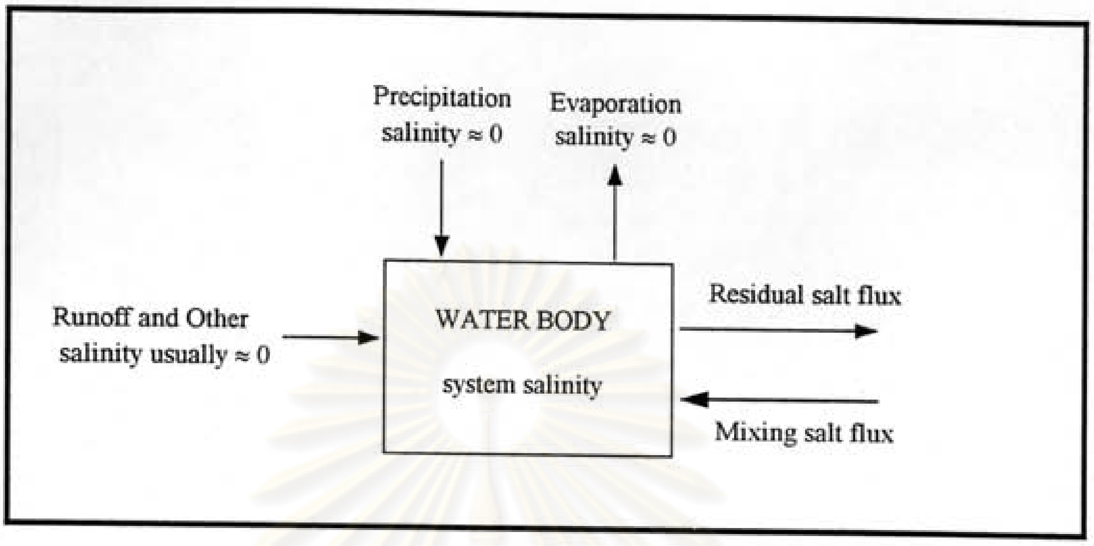

Figure 3.4 A simple box diagram of the salt budget in the coastal water body.

then some more complex form of water circulation analysis (numerical models of water circulation) may be feasible to be developed. The output from such numerical circulation models may subsequently be substituted for water and salt budgets in the order to estimate water exchange.

Nonconservative materials budget

The budget of nonconservative materials were constructed using some criteria as for water and salt budget. A simple box diagram illustrating the nonconservative material budget in the coastal water body is shown as Figure 3.5. This model can be used for any reactive material, the particular interest is in the balance among the essential plant nutrient elements C, N and P. Water exchange, defined by the water and salt budgets, describes the exchange fluxes of these elements along with salt. Clearly, total C, N and P are conserved, but these elements may be transformed from measured (such as dissolved) to unmeasured (such as particulate or gaseous) phases. All phases of these are known to be involved in biochemical and abiotic reactions, so they are not likely to be conservative with respect to salinity. In case of salinity, the budget is exactly balanced by water exchange. In the case of dissolved C, N and P, the budgeted

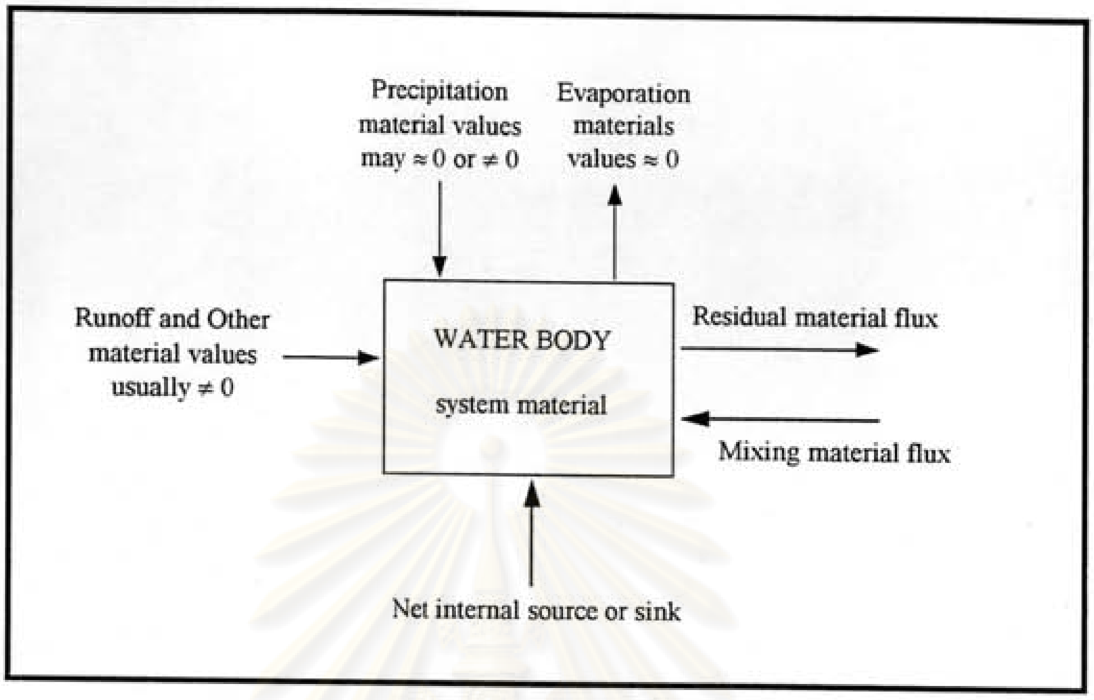

Figure 3.5 A simple box diagram of the nonconservative material budget in the coastal water body.

exchange fluxes are likely to leave some residual flux which is not balanced by these calculations. This residual for each element is a measure of the net internal fluxes (sources minus sinks) of these materials. In some cases, conservative behavior of these materials with respect to salt would be taken to reflect one or two conditions (or perhaps both): either the exchange rates of these materials in the water are fast relative to the internal fluxes, or conservative behavior represents the sum of uptake and release fluxes which cancel one another out.

To study the budget of nonconservative materials. There are two cautions that have to be considered. Firstly, it was pointed out above that water input from processes like groundwater and sewage could often be ignored, and that the contributions of these terms to the salt balance could usually be ignored. However, it should never be ignored for system receiving significant sewage input and should be done only with some caution for groundwater and precipitation. If there is coastal runoff, nutrient input from that runoff must be included in the budget.

Secondly, in order to construct very useful budgets for particle fluxes, for example, sediment input by stream and deposition within the system, salinity-based budgets must be treated with great caution in constructing budgets for particulate materials in shallow water systems. The reason is that dissolved materials have no gravitational component of flux within the water while particles do. Therefore particle distribution in the water column is likely to be extremely "patchy", with respect to both time and space, in areas subject to heavy loading with stream sediments, as well as in systems where wave mixing or active bioturbation is stirring the bottom sediments up into the water column. These processes can generate great heterogeneity in estimates of particle concentrations. While budgetary calculations for particles can be made according to the procedures to be outlines here, sampling artifacts may make the results quantitatively unreliable. As a result, the use of salt and water balance calculations are not generally useful to estimate particle budgets. It is worth recalling, however, that conservation of mass is a fundamental law of nature. Therefore, for materials without a gas phase, any deviation of dissolved forms of that materials from conservative behavior must present net uptake or release with respect of particles. This point is used in the interpretation of output from the budgets.

Methodological Background

Two approaches were used to establish nutrient budgets in the Upper Gulf of Thailand. One approach is the advection-diffusion model and the other approach is the box model.

Single longitudinal one dimension model
(The advection-diffusion model)

The single longitudinal one dimension model was constructed with the following assumptions:

1.) The Upper Gulf of Thailand was assumed as steady state condition and the water volume of the system was constant. The advective net volume exchange of the Upper Gulf is estimated from the balance between freshwater inflow, outflow, evaporation and precipitation. The precipitation over the Gulf was estimated from rainfall.

2.) The Upper Gulf was a one-dimensional system. The mixing of the water mass in the Upper Gulf was also considered in this model. Since the water mass of the Gulf can be assumed to be vertically homogeneous, except near the bay head and the lateral mixing is negligible (Snidvongs, 1993). Therefore, the Upper Gulf of Thailand is represented by a single longitudinal one dimensional model.

The order of magnitude of the longitudinal mixing is estimated from mixing volume :

$$\text{mixing volume } = \frac{K_x \cdot A}{\Delta x}$$

where the longitudinal mixing coefficient (K_x) $\approx 10^6$ cm^{2}s^{-1} for mixing length of the Gulf of 100 kilometers (Bowden, 1983), the Gulf cross-sectional area (A) $\approx 1.5\text{x}10^6$ m^2 and the distance along the north-south axis (Δx) $\approx 10^5$ m. The mixing volume of The Gulf was estimated to be 1500 m^{3}s^{-1} which is the same order as advective volume of 1000 m^{3}s^{-1} (the mean freshwater inflow to the Gulf). Therefore, the longitudinal mixing volume is one of the most important terms that should be considered in the budget model.

3.) Production and destruction were considered in terms of atmospheric deposition, source or sink. Total amount of these values will be estimated by other methods separated from the budget model.

4.) The regional and seasonal distribution patterns of hydrochemical variables indicate that, during wet season, the extension of the coastal zone increased from approximately 7 to 20 kilometers, while there was no difference in horizontal gradients of salt or nutrients from 20 kilometers from the head of the Gulf due to the vertically well mixed in water column (Figure 3.6). To determine the nutrient budget, the Upper Gulf of Thailand were divided into two areas, i.e. the coastal (< 20 km from the bay head) and the offshore (> 20 km from the bay head). In order to achieve this assumption, the boundary of study area was divided according to Department of Fishery's fixed stations (Figure 3.7). The boundary of the coastal box covered the

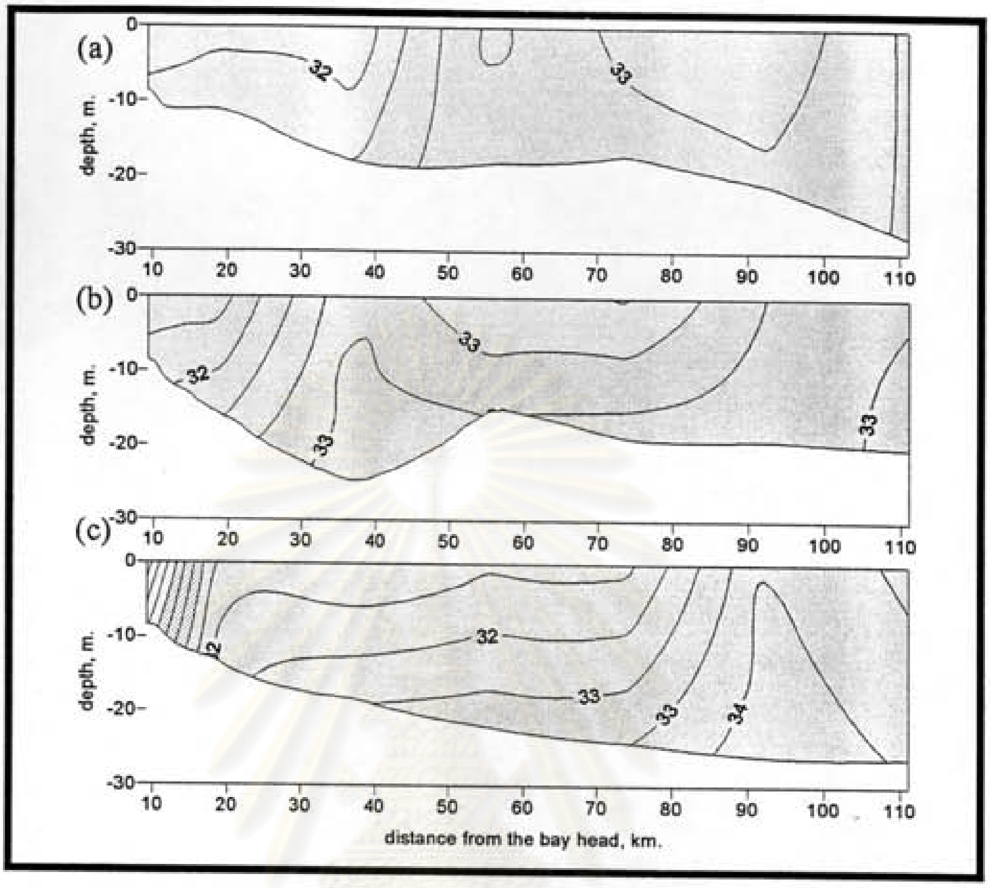

Figure 3.6 Vertical profile of salinity in (a) western part, (b) central part and (c) eastern part during wet period (September, 1989)

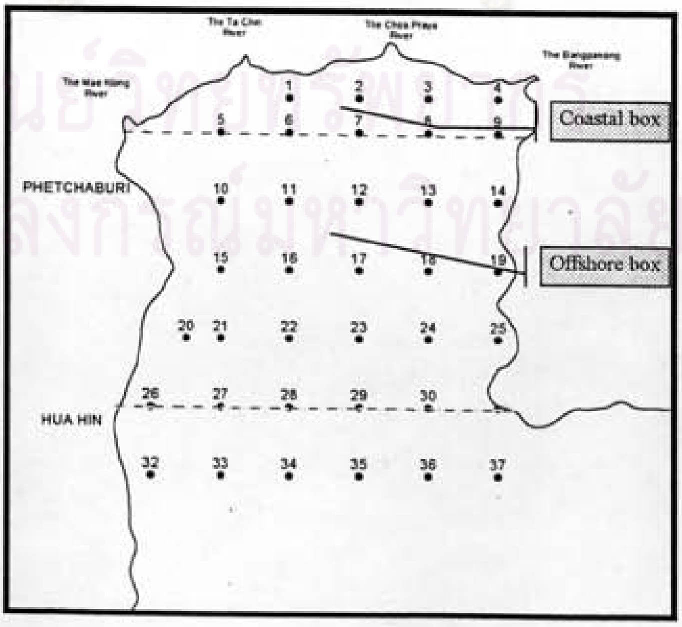

Figure 3.7 The coastal and offshore boxes boundary

station no. 5-9 which started from the bay head to 18.53 km, while the boundary of the offshore box covered the station no. 27-31 which started from 18.53 km to the bay mouth.

The difference flux in or out of the Upper Gulf was estimated in order to get the nutrient budgets. Volume and mass balance of water and salt (a conservative tracer) were used to estimate the two horizontal transport, advection and mixing terms.

Water Budget

Water balance in the Upper Gulf was expressed by the volume fluxes (in volume per time) of the inflow (Q_{in}), the outflow (Q_{out}), precipitation (P) and evaporation (E) as:

$$\frac{dV}{dt} = Q_{in} - Q_{out} - E + P \tag{3.4}$$

where $\frac{dV}{dt}$ was volume changes in the Upper Gulf with time and was assumed to be constant ($\frac{dV}{dt} = 0$).

Salt Budget

The salt content changes with time in the Gulf ($\frac{dVS}{dt}$) was expressed as follows:

$$\frac{dVS}{dt} = Q_{in}S_{in} - Q_{out}S_{out} - ES_e + PS_p - K_xA_x\frac{dS}{dx}\bigg|_{in} + K_xA_x\frac{dS}{dx}\bigg|_{out} \tag{3.5}$$

where S_{in}, S_{out}, S_e and S_p were salt concentrations of the water inflow, of the water outflow, of the evaporative outflow and of the precipitative inflow, respectively. The last two terms in Equations (3.5) were salt exchange flux in and out between the interested system and the outside. This exchange flux can be considered to be mixing term which consists of longitudinal mixing coefficient (K_x), cross-section area (A_x) and distance along the north-south axis (x). To simplify Equations (3.5), salt concentrations of the evaporative outflow and of the precipitative inflow were assumed to be zero. The system was considered as a steady state, so Equations (3.5) equals zero. Numerical solutions for each $K_{x,\,in}$ and $K_{x,\,out}$ were obtained by combination of Equations (3.4) and (3.5), and substitution of the salinity gradient term by estimating the relationship between salinity and distance from the bay head (Appendix D).

Nutrient Budget

Nutrients which are non-conservative substances can be assumed to be represented be the inputs and outputs as govern the water and salt. Thus, the advection and mixing exchange used for water and salt are well applied to nutrients. Equations (3.5) was modified to include the sum of the non-conservative process, R, (production or destruction term). Then the changes of nutrient content in the Gulf with time ($\frac{dVC}{dt}$) is described as follows:

$$\frac{dVC}{dt} = Q_{in}C_{in} - Q_{out}C_{out} - EC_e + PC_p - K_xA_x\frac{dC}{dx}\bigg|_{in} + K_xA_x\frac{dC}{dx}\bigg|_{out} + \mathrm{R} \qquad (3.6)$$

where C_{in}, C_{out}, C_e and C_p are nutrient concentrations of the water inflow, of the water outflow, of the evaporative outflow and of the precipitative inflow, respectively. The nutrient concentrations of the evaporative outflow and of the precipitative inflow are likely to be small and were considered to be zero. Then Equations (3.6) was simplified as:

$$\frac{dVC}{dt} = Q_{in}C_{in} - Q_{out}C_{out} - K_xA_x\frac{dC}{dx}\bigg|_{in} + K_xA_x\frac{dC}{dx}\bigg|_{out} + \mathrm{R} \qquad (3.7)$$

All terms are determined in units of mass per time. Steady state was assumed, therefore $\frac{dVC}{dt} = 0$. Thus, after substituting the appropriate hydrological and nutrient concentrations, R was calculated to balance the nutrient budgets.

Box model

The box model is The second approach which was used to describe the transport within the Upper Gulf in addition to advective and longitudinal mixing with some assumptions:

1.) Since, in some periods particularly wet season, there were some difference between the river runoff which drained into the eastern and western part of the Upper Gulf and there were extreme variations on precipitation and evaporation over the Upper Gulf. They affected on the water exchange between eastern and western part of the Upper Gulf. Consequently, the study area was divided into western and eastern segments and each segment was divided into small areas in order to estimate the internal transport of water and nutrients of the Upper Gulf in detail. In order to achieve this assumption, the boundary of study area was divided into six boxes, according to the Department of Fishery's fixed stations (Figure 3.8).

2.) The Upper Gulf was assumed as steady state condition. The water volume changes in the system with time can be considered as constant.

3.) Water and salt budget was constructed to estimate the hydrographic transport among the boxes (or estimate the internal trasportation of the Upper Gulf) with the net volume exchanges including exchange flow or mixing. Continuously, Nutrient budget was also constructed with the net material exchanges.

Water budget

The fundamental concept is the conservation of water mass. Therefore, the water volume change in the system during time may be represented by the balance between water inflows (the volume fluxes of freshwater runoff, the direct fluxes of precipitation, the advective inflow and the others inflows such as groundwater and sewage, Q_{in}) and outflows (evaporation and advective outflows, Q_{out}). In case of the Upper Gulf of Thailand, freshwater runoff, precipitation and the advective inflows are denoted the term of water inflows to the system because other inflows are likely to be small and can be ignored. Then the change of water volume in the Upper Gulf with time can be expressed as follows:

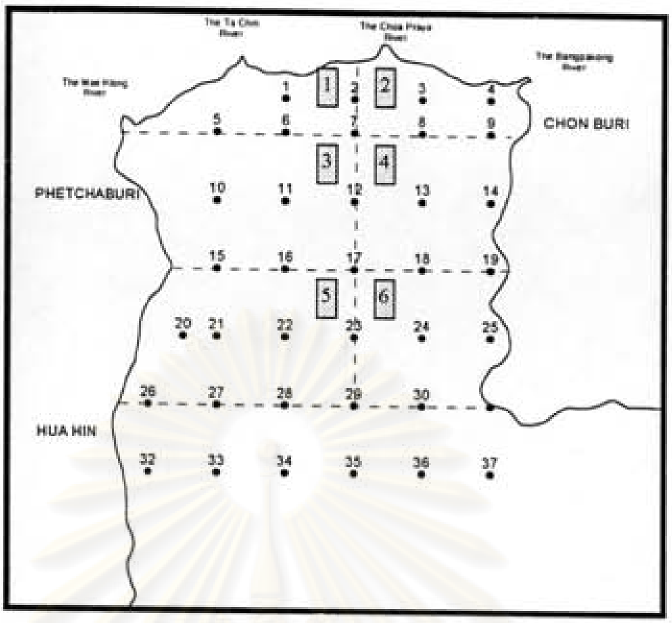

Figure 3.8 The six boxes boundary

$$\frac{dV}{dt} = \sum Q_{in} - \sum Q_{out} \tag{3.8}$$

In application, the change of water volume with time ($\frac{dV}{dt}$) is considered constant. The freshwater runoff, precipitation and evaporation are known from the measurement, so the simple calculations can be made to estimate the difference terms of advective inflows and outflows (cannot be solved individually). All terms are determined in the units of volume per time.

Salt budget

The salt content changes in the water type with the difference between salt flux, volume flux multiplied by salinity, in and outflows. This represent all of the hydrographic inputs and outputs (including in this case exchange flow in and out). The salt balance for the system can be described as flows:

$$\frac{dVS}{dt} = \sum Q_{in}S_{in} - \sum Q_{out}S_{out} \tag{3.9}$$

where water volume inflows and outflows are represented by Q_{in} and Q_{out} respectively and the salinity of water inputs and outputs are represented by S_{in} and S_{out}

respectively. In applications, the system of the Upper Gulf can be assumed at steady state ($\frac{dVS}{dt} = 0$) and the salinity of freshwater discharge, precipitation and evaporation are likely to be small and can be ignored, simplifying the Equations. Q_{in} and Q_{out} can be solved to evaluate individually by combining Equations (3.8) and (3.9). The appropriate salinity to use for each of the volume flux is the average salinity at the boundary of the boxes. For the boxes affected the freshwater, surface salinity is used instance of average salinity.

Nutrient budget

According to the criteria established by water and salt budget, nutrient budgets can be expressed as follows:

$$\frac{dVC}{dt} = \sum Q_{in}C_{in} - \sum Q_{out}C_{out} + \mathrm{R} \qquad (3.10)$$

Nutrients are involved in biogeochemical processes, so they are certainly not to be conservative. The nutrient exchange fluxes are probable to leave some residual flux which is not balanced by water and salt exchange. Thus, the residual flux or the net internal flux of nutrients have to included into the budget to balance the nutrient in the system and to describe how nonconservative processes act in the system (add or remove). The last term in Equations (3.10), R, represents the net internal flux of nutrients in the system. This term is in unit of mass per time.

To solve the Equations, the change of nutrient concentration with time, $\frac{dVC}{dt}$, was considered to be at steady state. It was also assumed that the concentrations of nutrients in the precipitative and evaporative water were zero.