SALINITY DISTRIBUTION AND PREDICTION IN MAJOR ESTUARIES IN SELANGOR DARUL EHSAN

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BY

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DEDICATED TO :

MY BELOVED FATHER AND MOTHER,
NGOR, SIANG, HONG,
AND KIM.

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LIST OF ABBREVIATIONS

A	Cross Section Area
C^H	Concentration at HW
C^L	Concentration at LW
C_o	Fresh Water Concentration (= 1)
D	Mean Depth at LW
L	Total Length of Estuary
P	Tidal Prism
R	River Discharge per Tidal Cycle
S_d	Salinity at Depth Below Water Surface
$\{S\}$	Vertical Mean Salinity of Station
V	Segment Volume
W	Mean Estuary Width at HW
X	Distance From the River Mouth
Z	Mean Depth at HW
BRM	Estuary of Sg. Bernam
HS	Highly Stratified
HW	High Water
KLG	Estuary of Sg. Klang
LGT	Estuary of Sg. Langat
LW	Low Water
NP	Neap Tide
PM	Partially Mixed
SEL	Estuary of Sg. Selangor
SHS	Slight Highly Stratified

SPM	Slightly Partially Mixed
SP	Spring Tide
WM	Well Mixed
a	Mixing Parameter
b	arbitrary section of vertical salinity profile
d	Depth Below Water Surface
n	Segment Number (n = 1,2,3,...,N)
ppt	Parts per Thousand
tc	Tidal Cycle

ABSTRACT

This is the first comparative study of the salinity patterns of Bernam River estuary, Selangor River estuary, Klang River estuary and Langat River estuary in Selangor Darul Ehsan. The behaviour of the estuaries was determined by salinity structure classification using a stratification diagram. Generally, the mixing pattern from spring tide to neap tide of Bernam River estuary is partially mixed; the Selangor River estuary varied from partially mixed to slight highly stratified; the Klang River estuary varied from partially mixed to highly stratified; and the Langat River estuary varied from well mixed to highly stratified. The simple segmented tidal prism model has been used to illustrate mixing and salinity distribution in well to partially mixed estuaries. The application of this model to these four river estuaries was assessed in this study. A comparison of the predicted and observed salinity data is made and discussed. Thirteen out of sixteen models for each tide condition of the four estuaries were successfully well predicted. The tidal prism model was modified to account for those with greater differences between predicted and observed data.

ABSTRAK

Ini adalah pengajian perbandingan corak kemasinan muara-muara Sg. Bernam, muara Sg. Selangor, muara Sg. Klang dan muara Sg. Langat di Selangor Darul Ehsan yang pertama. Kelakuan muara-muara ditentukan oleh klassifikasi struktur kemasinan menggunakan rajah stratifikasi. Secara umum, corak percampuran dari pasang perbani ke pasang anak bagi muara Sg. Bernam ialah 'percampuran separa'; muara Sg. Selangor berubah dari 'percampuran separa' ke 'sedikit tinggi pelapisan'; muara Sg. Klang berubah dari 'percampuran separa' ke 'tinggi pelapisan'; dan muara Sg. Langat berubah dari 'percampuran penuh' ke 'tinggi pelapisan'. Model 'Pasang Prisma Segmen Ringkas' telah digunakan untuk menerangkan percampuran dan pertaburan kemasinan bagi muara-muara 'percampuran penuh' ke 'percampuran separa'. Pemakaian model ini ke atas keempat-empat muara telah dinilai di dalam kajian ini. Perbandingan antara data kemasinan ramalan dan pemerhatian telah dibuat dan dibincangkan. Tigabelas daripada enambelas model bagi setiap keadaan pasang-surut untuk keempat-empat muara telah berjaya diramal dengan baik. Model 'Pasang Prisma' telah diubahsuaikan untuk mengambilkira data antara ramalan dan pemerhatian yang mempunyai perbezaan yang lebih besar.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Estuaries are important features of the coastal ecosystem and act as transitional zones between fresh and salt waters. Estuaries are also significant to human welfare through their role in transportation and navigation, production of food (aquatic resources), waste disposal and various recreational pursuits. In Malaysia, generally, and in Selangor, particularly, the main uses of estuaries are for commercial fishing, local transportation and waste disposal.

Recently, many of our estuaries have been affected by a rapidly growing society, accelerated development of industries along their shores, and are overloaded with human, agricultural and industrial waste products and effluents. Studies have been carried out in Klang River regarding estuary pollution. High feacal coliform counts detected in Klang River reveal that the river is being heavily polluted by domestic sewage discharge (Law, 1980). The results from Law and Singh (1986) study's on distribution of heavy metals indicated that the Klang estuary is polluted with lead, manganese and iron.

In the studies of estuaries, the pattern of exchange or mixing of fresh water and salt water are of primary importance in determining the behaviour of the estuary. Salinity is an indicator of this mixing. Therefore, salinity distribution is an essential parameter. These characteristics will be the main criteria for the determination of estuary behaviour.

Owing to the unique behaviour which occurs in estuaries, they actually act as traps for pollutants as well as nutrients which have entered to this region. The trapped pollutants such as heavy metals may be a hazard to human health if contaminated fish and shellfish harvested from this region is consumed. The mixing of any other properties of the water, such as pollutants introduced by cities and industries, and any material dissolved or suspended in the water may be linked to salinity.

It is essential that we should begin to protect and manage our estuaries if they are to remain as viable, multiuse environments. Studies of the behaviour of the estuaries and attempts to model them are among the approaches to achieve management purposes. These two will be the main approaches in this project study.

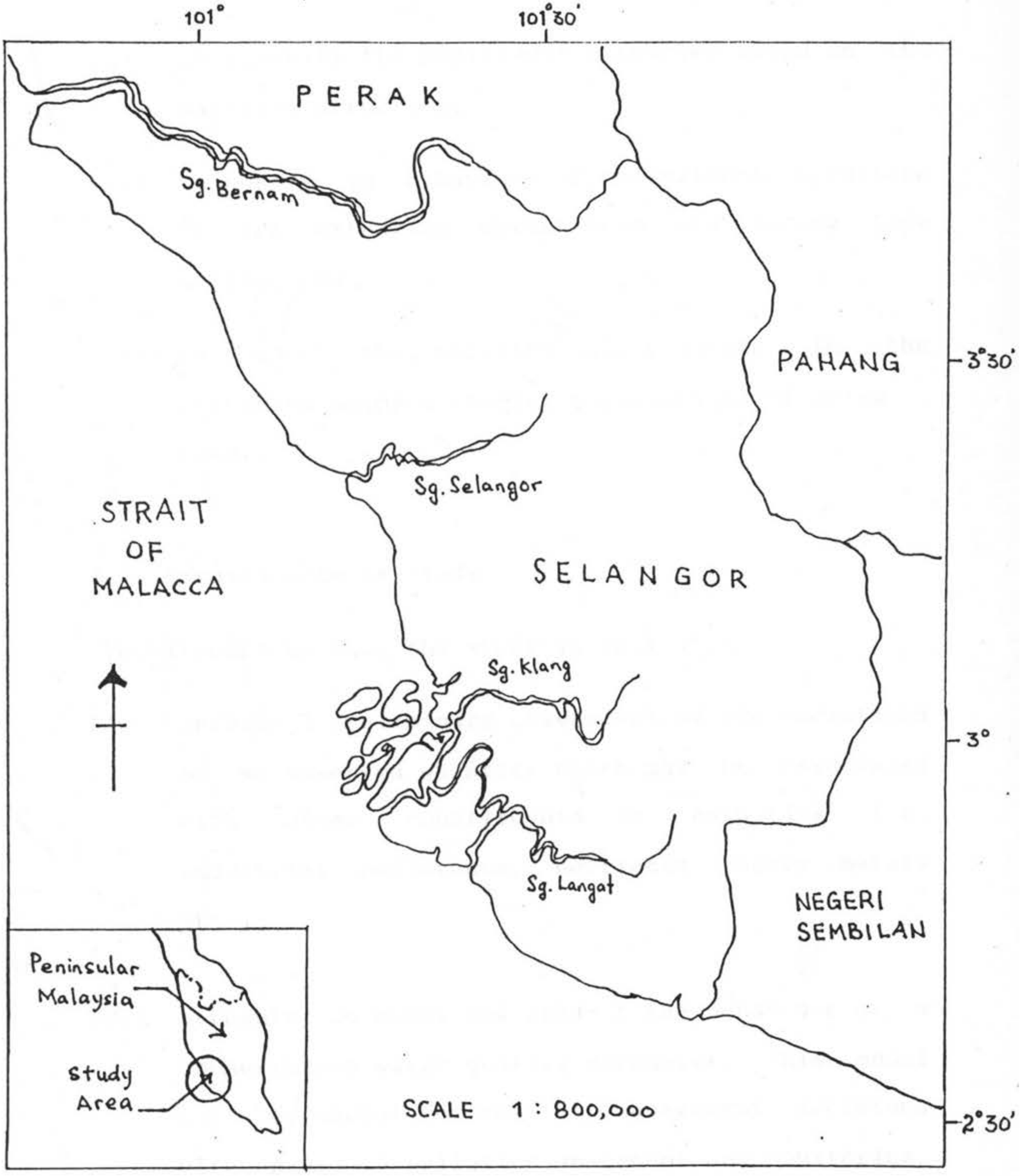
In this project study, a simple, segmented tidal prism model introduced by Dyer and Taylor (1973) is used to predict the salinity distribution of estuaries. In the model the parameters used are the physical dimensions (width, depth and length) of the estuary, tidal prism, river discharge per tidal cycle, and a mixing parameter. The model attempts to predict average conditions in successive volume segments of an estuary for a constant rate of river flow and for the mean tidal range. The assumptions are that steady state salinity distribution and complete mixing will exist throughout the estuary.

This model has considerable merit, in that it considers the mixing processes in an easily visualised, if over simplified, way. It has appeared to give quite satisfactory results when applied to test cases, in particular to the prediction of salinity distribution for the Thames estuary, UK, (Dyer and Taylor, 1973). Successful application of the model to the Raritan River, USA, (Dyer and Taylor, 1973) and the Thames (Dyer and Taylor, 1973) suggested that the model may be applicable to other estuaries.

1.2 Location of Study Area

Four major estuaries in Selangor Darul Ehsan were selected for studies. These are the estuaries of Sg.Bernam, Sg.Selangor, Sg.Klang and Sg.Langat (figure 1.1).

Figure 1.1 Location of study area



1.3 Objectives of Project Study

The objectives of the study are :-

(i) to classify the individual estuaries based on the salinity structure,

(ii) to observe the behaviour of the salinity structure in the estuaries during neap and spring tide cycles, and

(iii) to model the salinity distribution in the estuaries using a simple, segmented tidal prism model.

1.4 Significance of Study

The significance of the study is that it

(i) permits a preliminary assessment of the variations in an observed quantity which may be associated with other constituents in estuaries i.e. industrial pollutants, nutrients, heavy metals etc.,

(ii) attempts to model and predict the behaviour of a conservative water quality parameter. This model may be useful for coastal management decisions with regard to pollution abatement and monitoring.

(iii) increases and improves the knowledge pertaining to salinity mixing and distribution in the estuaries. This will be the first comparative study of all four estuaries.

1.5 Structure of Thesis

There are five chapters in this project report. Chapter 1 discusses the general background including the objectives and significance of study. Literature reviews of past experiences related to the study is summarised in Chapter 2. Methods and materials used are described in detail in Chapter 3 to provide a better view of how the study was carried out. It is then followed by the findings, results and discussions in Chapter 4. The overall results are summarised in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Estuary : Definition

The word estuary is derived from the Latin word *aestus*, meaning tide, and the adjective *aestuarium*, meaning tidal. Generally, most people would recognize an estuary as a place where the river water which mix with salt water that enter from the sea through the river mouth. As an everyday definition, this may seem perfectly satisfactory, but it gives no indication of how far up-river an estuary extends or of the interaction between the fresh river water and the saline sea water.

What is an estuary by definition ? Let us first consider what is meant by an estuary. Many definitions have been given, for instance :

a) "*An estuary is that part of the lower course of a river affected by tides, and its extent depends upon the tidal range.*" (Twenhofel, 1950)

b) "*An estuary may be defined as a body of water in which the river water mixes with and measurably dilutes sea water.*" (Ketchum, 1951)

c) "*An estuary is an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors : (a) a marine or lower estuary, in free connection with the open*

> *sea; (b) a middle estuary, subject to strong salt and freshwater mixing; and (c) an upper or fluvial estuary, characterised by freshwater but subject to daily tidal action."* (Fairbridge, 1980)

but Pritchard (1967) has given a more circumscribed definition, that is :

> *"An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea within which sea water is measurably diluted with fresh water derived from the land drainage."*

All of these definitions describe some of the same characteristics to an estuary, as Pritchard's definition, but there are some important differences. They all suffer in that they are either too inclusive or too exclusive.

2.2 Estuarine Circulation

Generally, there are three types of estuaries : there are highly stratified estuaries, partially mixed estuaries, and well mixed estuaries.

It was not yet possible to state precisely the relationships between the various physical factors such as depth and width, and the circulation and mixing in an estuary back in 1950's (Bowden, 1967). However, enough is now known so that the general character of estuarine circulation can be related to the more important physical phenomena such as river flow, tidal range, and the physical geography or dimensions (Bowden, 1967).

A scheme for the classification of estuaries based on the physical character of the circulation was proposed by Stommel (1953a), and its main features were adopted by Pritchard (1952b, 1955), Pritchard and Carter (1971), and Ketchum (1952, 1953) in reviews they made of the knowledge available at that time. Later work has confirmed the usefulness of this method of classification which is essentially that followed in Bowden's paper (1967). Another scheme of classification is based on salinity structure which has been described by Dyer (1973), Bowden (1967) and Pritchard (1952). This classification was used for the determination of estuarine behaviour in the study.

The basic factor in determining the type or behaviour of circulation is the role played by tidal currents relative to that of river flow in the estuary. As river water moves seaward, it becomes progressively more saline. This indicates that seawater is being entrained in the seaward flow of brackish water, and the total seaward flow is thereby augmented. In order to provide this seawater there must be a counter flow movement of more salty water having a net flow in a landward direction.

Highly Stratified Estuary

For a steady river flow and a particular estuary, the position of the tip of the highly stratified estuary and the shape of the salt wedge remains fixed (Pritchard and Carter, 1971). If the river flow reduces, the tip of the salt wedge moves landward and become sharper. If the river flow increases, the tip moves seaward and becomes blunter (Figure 2.1).

The tidal current, which do not result in any net transport of water over a complete tidal period on its' own, exerts a profound influence through the turbulent mixing it produces. This tends to break down the interface between the river fresh water and salt water and produce a mixing of the two waters through a part or whole of the vertical water column. Consequently, this would result in a partially mixed estuary.

Partially Mixed Estuary

In this type of estuary, the tide will be sufficiently strong to prevent the river from dominating the circulation. The situation occurs only if the volume flow of the tidal oscillation is much greater than the volume flow of the river. The added turbulence caused by the tidal prism provides the means of erasing the highly stratified estuary. Not only is salt water mixed upward but fresh water is mixed downward as well.

Figure 2.1 Salinity profiles in a Highly Stratified Estuary. (Source : Dyer, 1973)

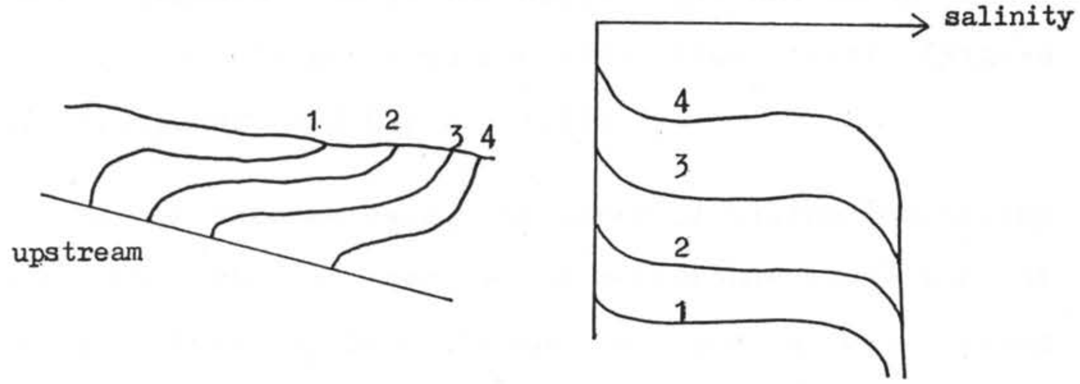


Figure 2.2 Salinity profiles in a Partially Mixed Estuary. (Source : Dyer, 1973)

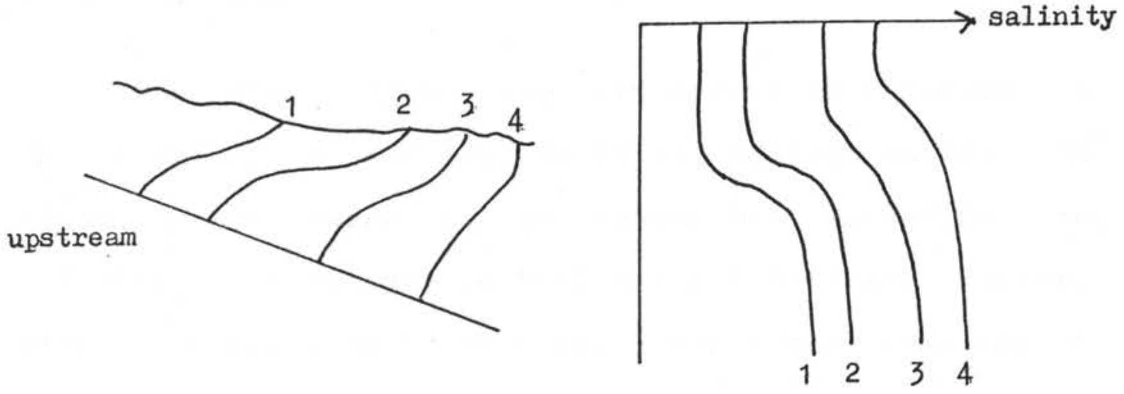
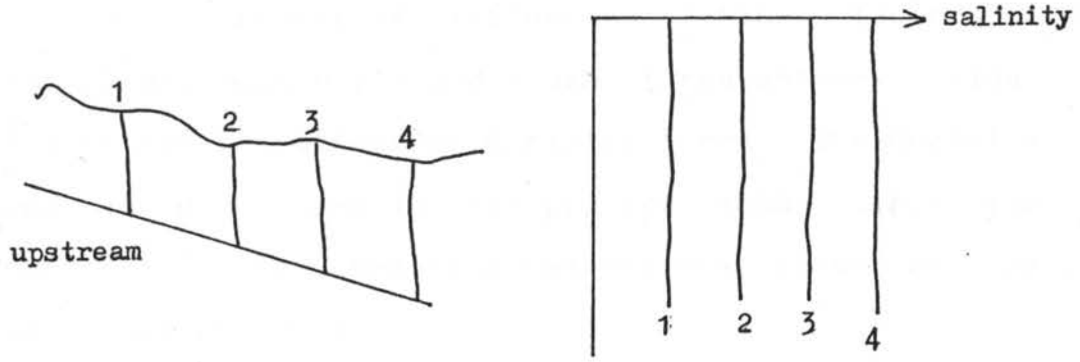


Figure 2.3 Salinity profiles in a Well Mixed Estuary. (Source : Dyer, 1973)



The net seaward flow in the upper layer may be an order of magnitude larger than the river flow itself (Figure 2.2) (Pritchard and Carter, 1971).

In an extreme case, the vertical mixing occurring is so thorough that there is no measurable variation of salinity from surface to bottom, and a well mixed estuary is formed.

Well Mixed Estuary

The tidal currents are very strong in relation to the river flow and the vertical mixing becomes so intense that there is no measurable variation in salinity from surface to bottom (Pritchard and Carter, 1971). However, there is still a horizontal gradient of salinity, increasing from the head to the river mouth (Figure 2.3) (Pritchard and Carter, 1971).

The interaction between the river discharge and the tidal currents are influenced by other factors : tide range, mean depth and width of the estuary, tidal velocity and the effect of Coriolis force. The Coriolis force is discounted in this project study since the location of the studied estuaries are close to the Equator (below 5^{o} N).

2.2.1 Relationships Between Physical Parameters and the Estuarine Sequence

According to Pritchard and Carter's (1971) proposal on the relationships between physical parameters and the estuarine sequence, the important physical parameters which control the sequence of estuarine types are the river discharge, the tide range, the mean depth of the estuary and the width of the estuary.

When the river discharge is such that the volume inflow during a tidal cycle is large compared to the tidal prism, the estuary will have the characteristic of highly stratified estuary. If the flow is decreased to a point where the tidal prism are large compared to the river discharge per tidal cycle, then the estuary will shows the behaviour of a partially mixed estuary. As the flow become still smaller the tidal velocity can more effectively overcame the vertical stability and the estuary will exhibit well mixed estuary.

If the river discharge and tidal velocity are kept constant, and the cross section area is varied by changing the width of the estuary, then the ratio of tidal volume to river discharge is changing in effect, since the same tidal velocity will pass a greater volume of water through a large cross section than a small one. Since it is the volume of water per unit time which is considered in the river discharge, a larger cross section implies lower net velocity related to river discharge alone. The net result of increasing the width of the estuary is then the same as that obtained by decreasing the river discharge. Hence, the estuary sequence would tend to shift from highly stratified estuary towards well mixed estuary for increasing width.

The effect of varying the depth, while holding the other parameters constant, is quite different from the effect of vary the width. An increase in depth does increases the cross section area and hence apparently decreases the ratio of river discharge to tidal prism. However, the increase in depth also results in lowering the effectiveness of the tidal velocity in promoting vertical mixing, and the system tends to become more highly stratified. The river outflow is therefore more effectively confined to the upper layer. The effect of increasing the depth would then in general have an opposite to that of increasing the width, and would correspond to decreasing the tidal velocity. The estuary sequence would tends to shift from well mixed estuary towards highly stratified estuary for increasing depth.

2.3 Simple Segmented Tidal Prism Model

The simple, segmented tidal prism model proposed by Dyer and Taylor (1973) was derived partly on

Ketchum's (1951) modified Tidal Prism Model and partly on Maximon and Morgan's model (1955).

From a physical standpoint, this model of the estuary has recognized in the distribution of salinity, as well as the circulation pattern and the mixing processes; it points out also the importance of the movement and mixing of waters.

The model attempts to predict average conditions in successive volume segments of an estuary for a constant rate of river flow and the mean tidal range. Two fundamental assumption were made i.e. :

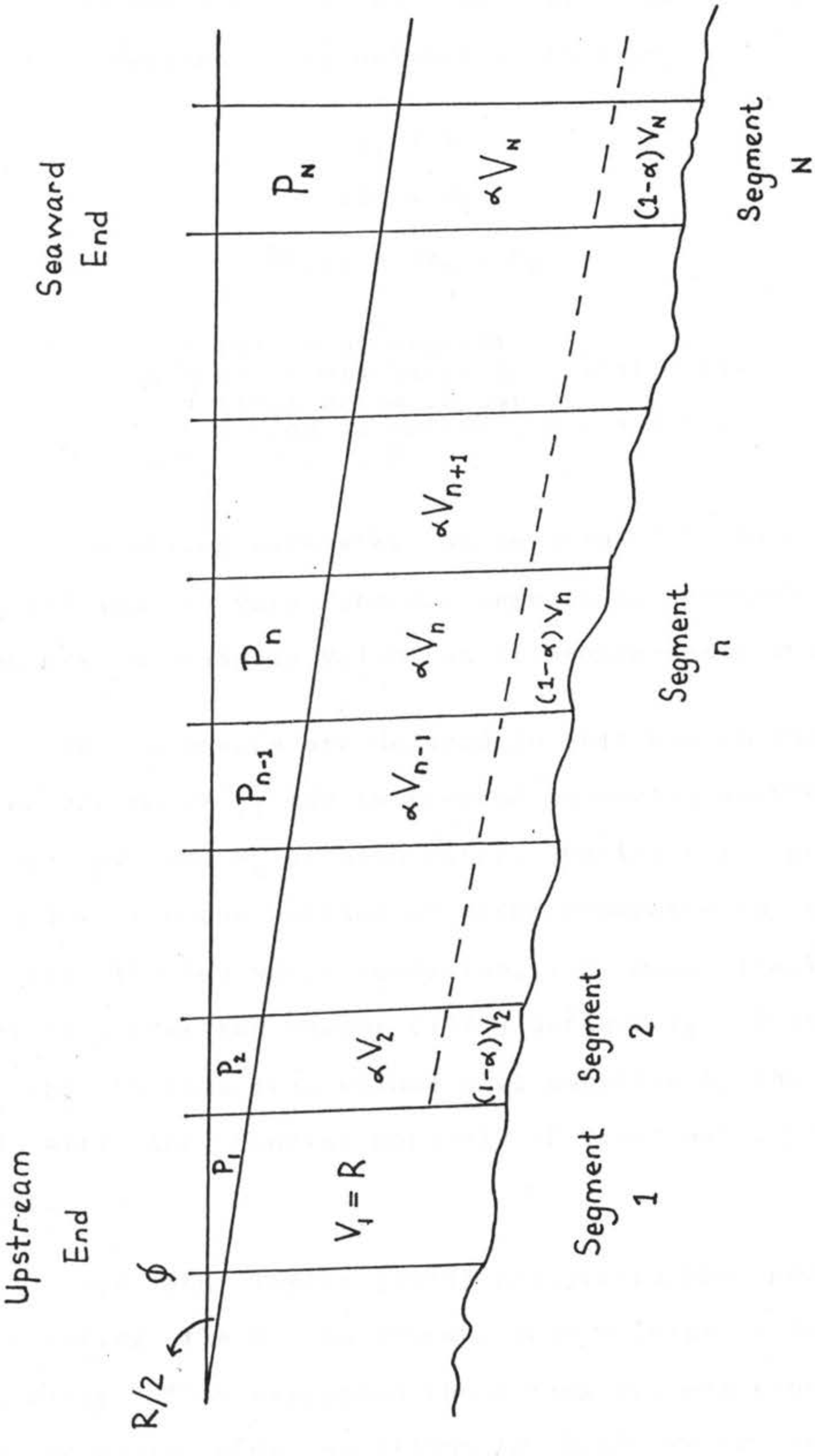
a) A steady state distribution of fresh and salt water will exist throughout the estuary;

b) Complete mixing will occur within the volume segments.

2.3.1 Segmentation

According to Ketchum's work (1951a, 1951b), the upper end estuary of the model is defined by that section which there is no net exchange or flow on the flood tide (Figure 2.4). Ketchum (1951a) defined that the volume of tidal prism above '0' was the river discharge volume over a full tidal cycle, R. The definition was found incorrect by Dyer and Taylor

Figure 2.4 Tidal prism segmentation of an estuary.
(Source : Dyer and Taylor, 1973)



(1973). Dyer and Taylor (1973) stated that the tidal prism volume above '0' will be R/2. Segment 1,2,...,N are then defined consecutively so that :-

$$V_1 = R$$

$$aV_2 = P_1$$

$$aV_{n+1} = aV_n + P_n \qquad (2.1)$$

where
V = volume of segment
R = river discharge per tidal cycle
P = tidal prism volume
a = mixing parameter ($0 < a < 1$)
n = 2, 3,..., N-1

Thus, the mixing parameter can be assumed to be constant or allowed to vary from one segment to another. The segments increase in volume as it progresses seaward.

The segments are defined in this way so that the water volume aV_{n+1} may be treated as moving upstream to occupy aV_n and P_n at high water. During this process, it mixes with the portion of water remaining in segment 'n' from the low water condition, i.e. with $(1-a)V_n$. In addition, Dyer And Taylor (1973) defined $V_1 = R$ so that on the ebb tide this volume will supplied by the river and will then consist entirely of river water at low water.

Dyer and Taylor (1973) formulated the model by considering the mixing process only at high water and low water. They expressed the mixing process concept in two separate model equations for high water and low water respectively, given as below :-

high water mixing

$$(V_n+P_n).C_n^H = aV_{n+1}.C_{n+1}^L + (1-a).V_n.C_n^L \; ; \; n \geq 2 \qquad (2.2a)$$

and

$$(V_1+P_1).C_1^H = V_1.C_1^L + aV_2.C_2^L \qquad (2.2b)$$

low water mixing

$$V_n.C_n^L = (aV_n+R).C_{n-1}^H + [(1-a)V_n - R)].C_n^H \; ; \; n \geq 2 \qquad (2.3)$$

An alternative relationship between the concentration is provided by the requirement that, across any section, there must be a net seaward flux of river water equal to RC_o on each tidal cycle. This gives

$$RC_o = (R + aV_{n+1}).C_n^H - aV_{n+1}.C_{n+1}^L ; \; n \geq 1 \qquad (2.4)$$

A simple relation between the C^L and C^H can be derived from equation 2.2 and 2.4, and results in following form :

$$C_n^H = \frac{RC_o + aV_{n+1}.C_{n+1}^L}{(R + aV_{n+1})} \qquad (2.5)$$

and

$$C_n^L = \frac{R.(C_o - C_n^H)}{(1-a).V_n} + C_n^H \qquad (2.6)$$

The final equation 2.5 and 2.6 are used in computation for the concentration of constituents associated in the water column in this study.

The advantage of this simple segmented tidal prism model is that it requires only knowledge of the river discharge, physical dimensions of the estuary and tide range. These are usually easily obtainable.

A knowledge of the salinity distribution is not required as parameter in the model. However, in this study field measurement of salinity is taken. It is treated as constituent associated in the water column for comparison between the computed and observed data and in turn to determine the validity of the model onto the studied estuaries.

One hypotheses concerning the mixing break down if $(1-a)V_n < R$. In equation 2.6 this would give rise to negative values of C_n^L. The appropriate interpretation proposed by Dyer and Taylor (1973) is that any salt water passing upstream into segment 'n' on the flood tide is entirely removed on the ebb tide so that $C_n^L = C_o$ and, in consequence $C_{n-1}^H = C_o$, $C_{n-1}^L = C_o$ etc.

Dyer and Taylor (1973) considered an idealized estuary in which $P_n = V_n$ and $a = 0.8$ which they believed to be a reasonable estimate for typical estuaries. The results given in Table 2.1 were from their computation using this model.

Table 2.1 Results for a model estuary $P_n = V_n$, $a = 0.8$ (Source : Dyer and Taylor, 1973).

seg.no.	aV_n/R	V_n/R	C^L/C_o	C^H/C_o
1	-	1.0	1.0	1.0
2	1.0	1.25	1.0	1.0
3	2.25	2.8125	1.0*	0.927
4	5.0625	6.328	0.912	0.582
5	11.391	14.239	0.545	0.299
6	25.63	32.04	0.271	0.137
7	57.67	72.08	0.122	0.056
8	129.7	162.2	0.049	0.019
9	292.0	364.9	0.015	0.002
10	656.8	-	0.0	-

* Note that $(1-a)V_3 < R$ and so $C^L_3 = 1.0$

2.4 Flushing Time

The average time required for the river water volume, to move through the estuary area is defined as the flushing time (Ketchum, 1950 & 1951b).

The flushing time, t_n, in terms of tidal cycle, for individual segments can be calculated by dividing the volume of fresh water in each segment of the tidal mean condition, V_n, by the river discharge per tidal cycle. Thus t_n is given by

$$t_n = \frac{V_n}{R} \qquad (2.7)$$

The summation will give the flushing time for the entire estuary, t_f, and is given as follow :

$$t_f = \frac{\Sigma V_n}{R} \qquad (2.8)$$

The flushing time as calculated in this way may be applied rigorously to a pollutant only if it is introduced into the estuary in the same way as the fresh water (Bowden, 1967). Thus if practically all the fresh water enters by a river at the upper-end of the estuary and the pollutant is also introduced at this point, the flushing time so calculated should apply closely to the pollutant. If, however, the pollutant is introduced into another part of the estuary, the flushing time for it may be different.

CHAPTER 3

MATERIAL AND METHODS

3.1 Location of Estuaries

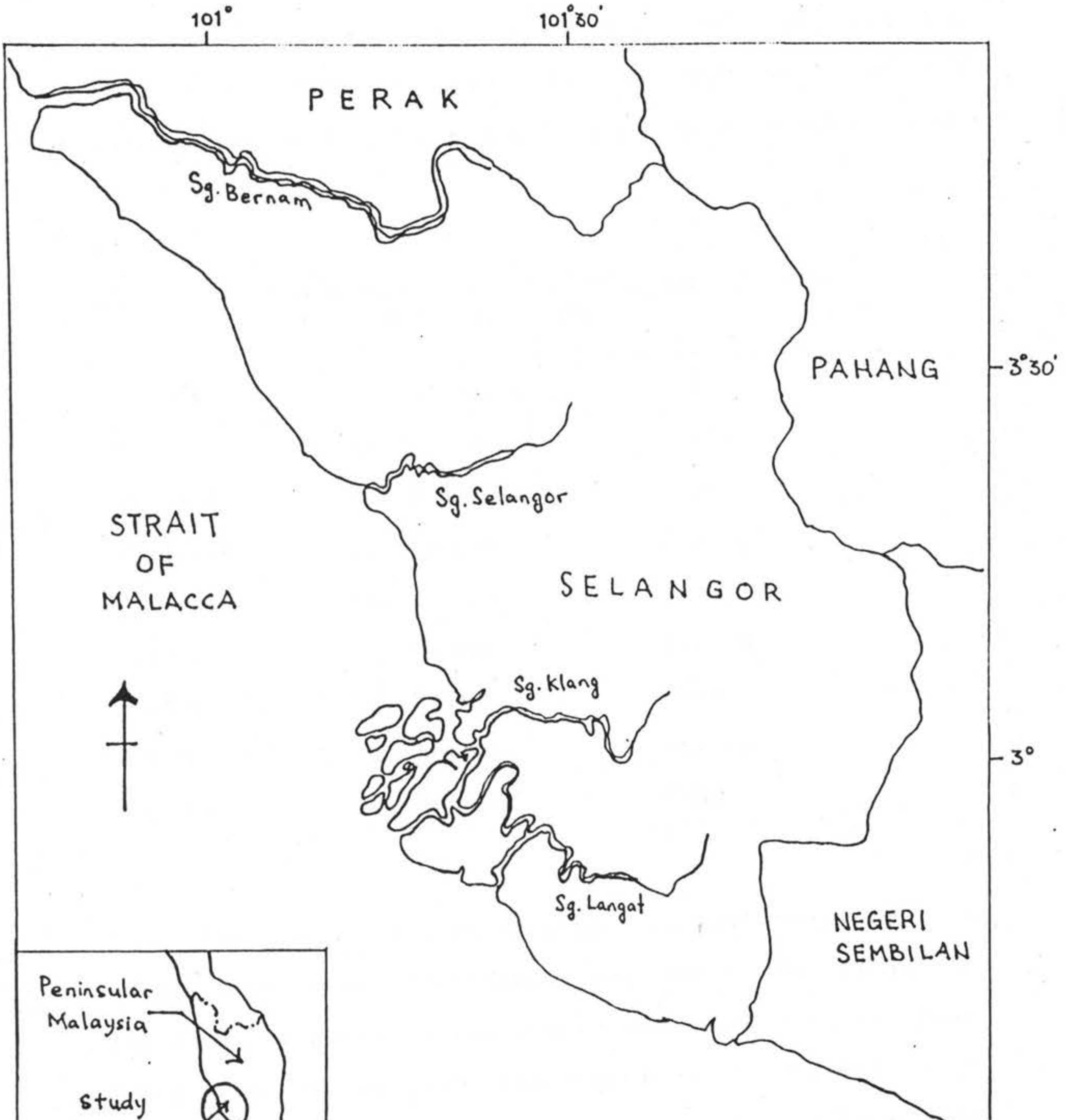
Studies have been carried out in four major estuaries in Selangor Darul Ehsan. These are the estuaries of Sg. Bernam, Sg. Selangor, Sg. Klang and Sg. Langat (Figure 3.1).

3.2 Survey Methods and Equipment

Five to ten stations are established depending on the length of the estuary. A station number was allocated for each station. The main criterion in establishing a station was according to the salinity distribution variation along the estuary.

Sampling was conducted during spring and neap tide at high water and low water. The date of spring and neap tides were determined from the 'Tide Table of Malaysia 1991' and 'Tide Table of Malaysia 1992' published by the Malaysia Survey and Mapping Department. The data of Port Klang recording station were used to predict for Sg.Klang, Sg.Langat and Sg.Selangor while for Sg.Bernam data of Lumut seaport was used. The dates on which sampling were carried out for the whole project is listed below (Table 3.1).

Figure 3.1 Location of study area



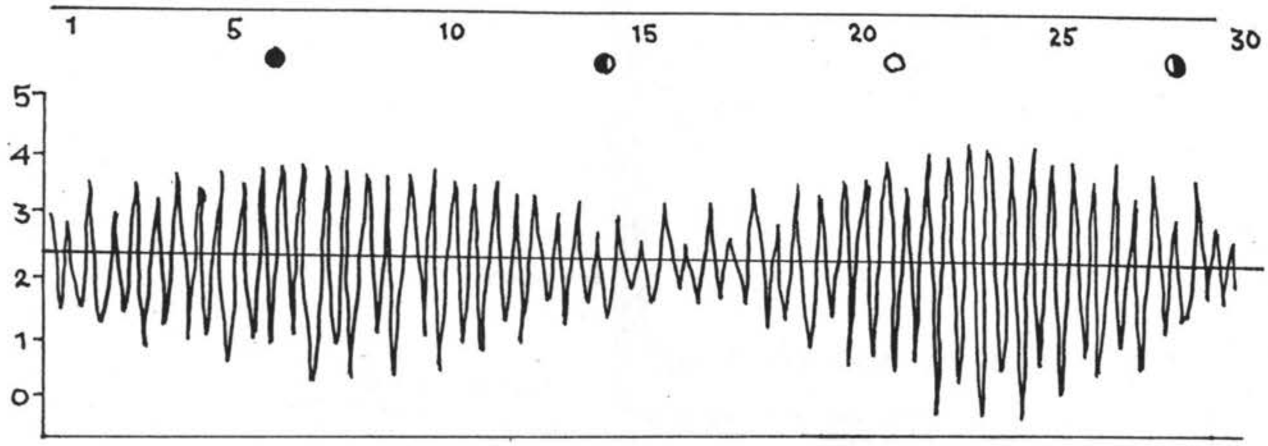
On the sampling day, the field measurements were began one and a half hours before high water or low water occurs. It is to ensure the measurements completed within the time range of high water or low water right to the upper-end of estuary or to the river mouth.

Table 3.1 The sequence of sampling dates during spring and neap tides.

DATE	ESTUARY OF	TIDE
17/9/91	Sg. Selangor	Spring
24/9/91	Sg. Selangor	Neap
17/10/91	Sg. Langat	Spring
23/11/91	Sg. Langat	Neap
8/12/91	Sg. Klang	Spring
15/12/91	Sg. Klang	Neap
7/1/92	Sg. Bernam	Spring
15/1/92	Sg. Bernam	Neap

The predicted time of occurring high water or low water were also determined from the Tide Table of Malaysia by plotting the hourly sea level data of Port Klang recording station from September to December 1991 onto a graph (Figure 3.2). The actual time of high and low water was assumed to be similar to that predicted.

Figure 3.2 Semidiurnal tides at Port Klang station (Example : December, 1991 data).

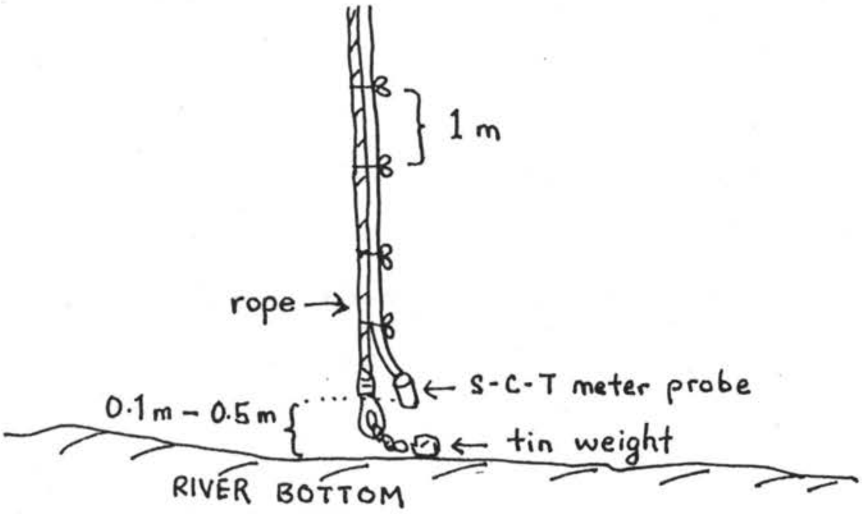


Two *in situ* parameters were taken, i.e. temperature and salinity by using a YSI S-C-T meter model 33. The parameters readings were taken at several depth for each station. If there is a sharp changes of salinity reading exceeds 10ppt between one depth and next 1m depth, the reading at half of this particular water column was recorded.

The probes were attached to a rope at about 0.5m to 1m (Figure 3.3). This rope was marked half meter intervals. The rope together with the probe was lowered by hand for every salinity measurements. The total depth of the water column was calculated as the depth of the rope hooked with sufficient tin weights when resting at the bottom plus 0.1m to 0.5m, as the 0m marked on the rope was 0.1m to 0.5m above the base of the tin weights.

Sampling was carried out at the mid channel of the four estuaries.

Figure 3.3 Diagram showing setting up of the measuring probe.



3.3 Data Analysis

Salinity profile graphs of each station for all estuaries during spring and neap tides at both high water and low water were plotted in order to determine the behaviour of estuaries, and the average salinity value for that particular station was observed. These average salinity values were calculated by dividing the profile into 10 sections or "boxes". In each section, the centre salinity value is assumed as mean of a particular region. The top and bottom sections were considered covering only half of the section. Hence, the calculation for the average value for the salinity profile is as below :-

$$\frac{1/2*b_1 + \sum_{i=2}^{10} b_i + 1/2*b_{11}}{10} \qquad (3.1)$$

where b is the sections or 'boxes' divided vertically from surface salinity profile (b_1) to bottom salinity profile (b_{11}).

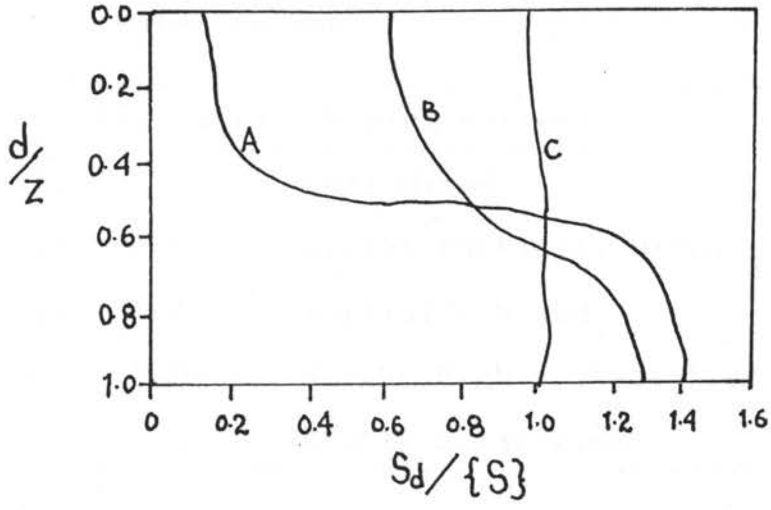
These average salinity values for each station were then plotted against estuary distance. The average salinity values were then used to compare with the predicted model curve data.

3.3.1 Salinity Mixing Ratio

In determining the type of behaviour which occurs during spring and neap tide at high water and low water, a modified stratification parameter classification introduced by Ippen and Harleman (1961) was used. The relative depth, d/Z (where d is the depth below water surface and Z is the mean depth of the estuary) was plotted against the relative depth salinity to the mean salinity of that particular station, $S_d/\{S\}$ (where S_d is the salinity at the depth below water surface and {S} is the vertical mean salinity of particular station) as shown in Figure 3.4. Line 'A' shows a highly stratified estuary, line 'B' shows a partially mixed estuary and line 'C' represents a well mixed estuary.

Specifically, the behaviour of the estuary was divided into five different type of classification. These are Well Mixed Estuary (WM), Slightly Partially

Figure 3.4 Salinity Mixing Diagram



Mixed Estuary (SPM), Partially Mixed Estuary (PM), Slight Highly Stratified Estuary (SHS) and Highly Stratified Estuary (HS).

The criteria used in determining the classification of the estuary is the difference between the salinity ratio at the bottom and the salinity ratio at the surface of particular water column in the estuary. The range of the different salinity ratio suggested for the five classification is listed in Table 3.2.

The suggested different salinity ratio range diagram (Figure 3.5) is reasonable for the classification as it shows approximately the same diagram to that stratification parameter classification diagram by Ippen and Harleman (1961) (Figure 3.6).

Table 3.2 Classification of the behaviour of estuary by the difference of salinity ratio between the bottom and the surface of particular water column.

Diff. sal. ratio	Mixing Pattern
≤ 0.20	Well Mixed
0.21 - 0.40	Slight Partially Mixed
0.41 - 1.00	Partially Mixed
1.01 - 1.20	Slight Highly Stratified
> 1.20	Highly Stratified

3.3.2 Simple Segmented Tidal Prism Model

The simple, segmented tidal prism model was programmed into computer. It was written in TURBO PASCAL language version 5.5. The program print out is listed in Appendix A.2 and A.3. The program was tested with the sample values given by Dyer and Taylor (1973) before it was used to analyse and predict the data obtained from this study.

This model computer program needs three input parameters in order to executing analysis, i.e. river discharge per tidal cycle (R), physical dimension of the channel (for segment volume calculation, V), and a mixing parameter constant (a).

The river discharge data for each estuary or river were obtained from Drainage and Irrigation Department

Figure 3.5 Salinity ratio difference range for the five classification of estuary behaviour.

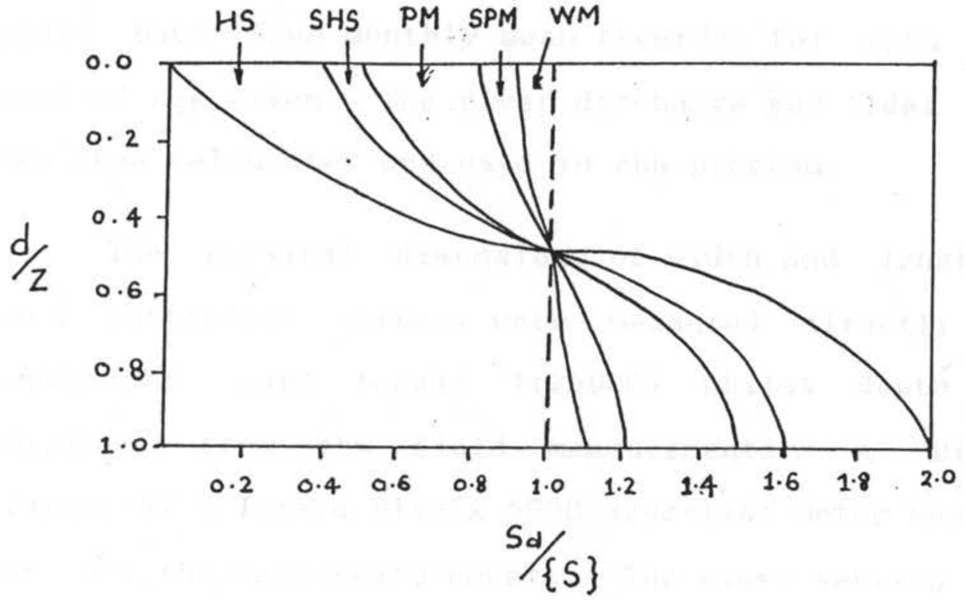
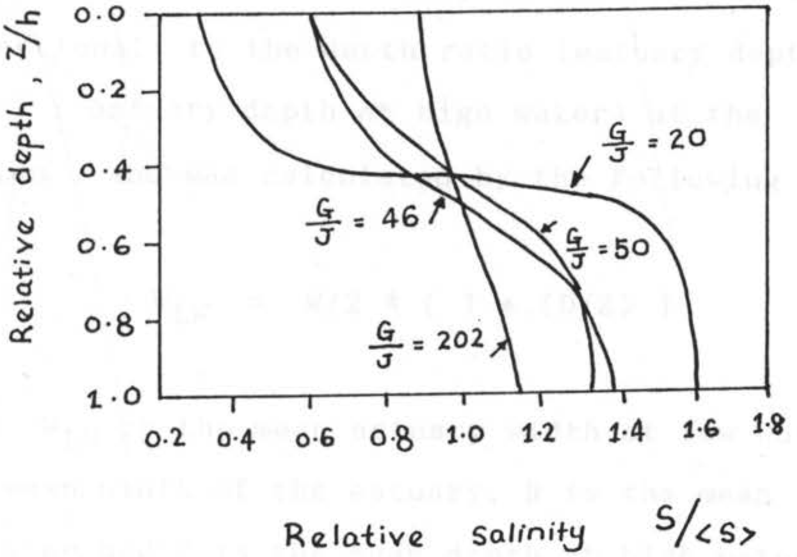


Figure 3.6 Vertical salinity gradients in relation to stratification number (Source : Ippen and Harleman, 1961).



(DID) records. The mean river discharge of 5 to 10 years back from monthly mean records for each river studied was taken. The river discharge per tidal cycle was then calculated and used in the program.

The physical dimensions of width and length of each particular estuary were measured directly from topography maps (scale 1:25000) whilst depth was obtained from the field measurements. A Digital Planimeter - Tamaya Planix 5000 area-line meter was used for all the maps measurements. The cross section area along the estuaries were assumed to have a trapezium shape (Figure 3.7). The surface water width of cross section during high water is assumed to be twice the width at the bottom, and measured from topography maps. The width of estuary at low water is assumed proportional to the depth ratio (estuary depth at low water : estuary depth at high water) at the particular station , and was calculated by the following equation :

$$W_{LW} = W/2 * [1 + (D/Z)] \qquad (3.2)$$

where W_{LW} is the mean estuary width at low water, W is the mean width of the estuary, D is the mean depth at low water and Z is the mean depth at high water.

In addition, two equations for the calculation of cross section area at both high water and low water were used as given below :

Figure 3.7 Assumption for trapizium cross section area of an estuary.

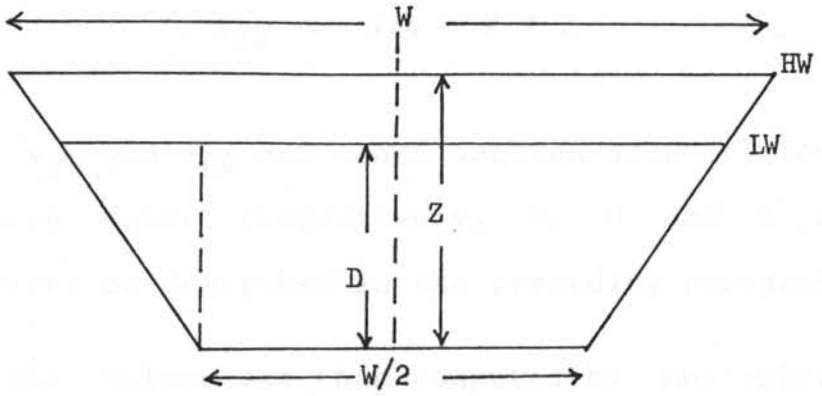
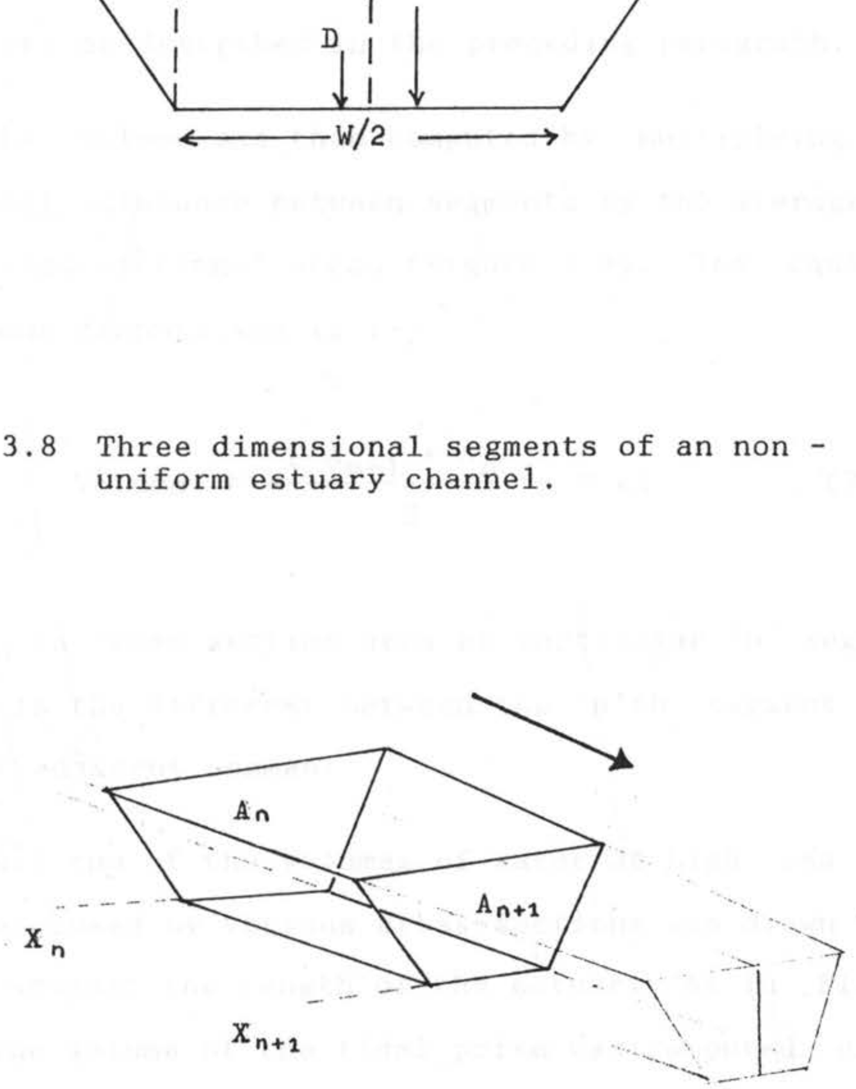


Figure 3.8 Three dimensional segments of an non - uniform estuary channel.



$$A_{LW} = W/2 * \{ 1 + [D/(2*Z)] \} \tag{3.3}$$

$$A_{HW} = 3/4 * W * Z \tag{3.4}$$

where A_{LW} and A_{HW} are cross section area at low water and high water respectively, W, D and Z are the parameters as described in the preceding paragraph.

The volume was then computed by multiplying the horizontal distance between segments by the average of their cross-sectional areas (Figure 3.8). The equation for volume computation is :-

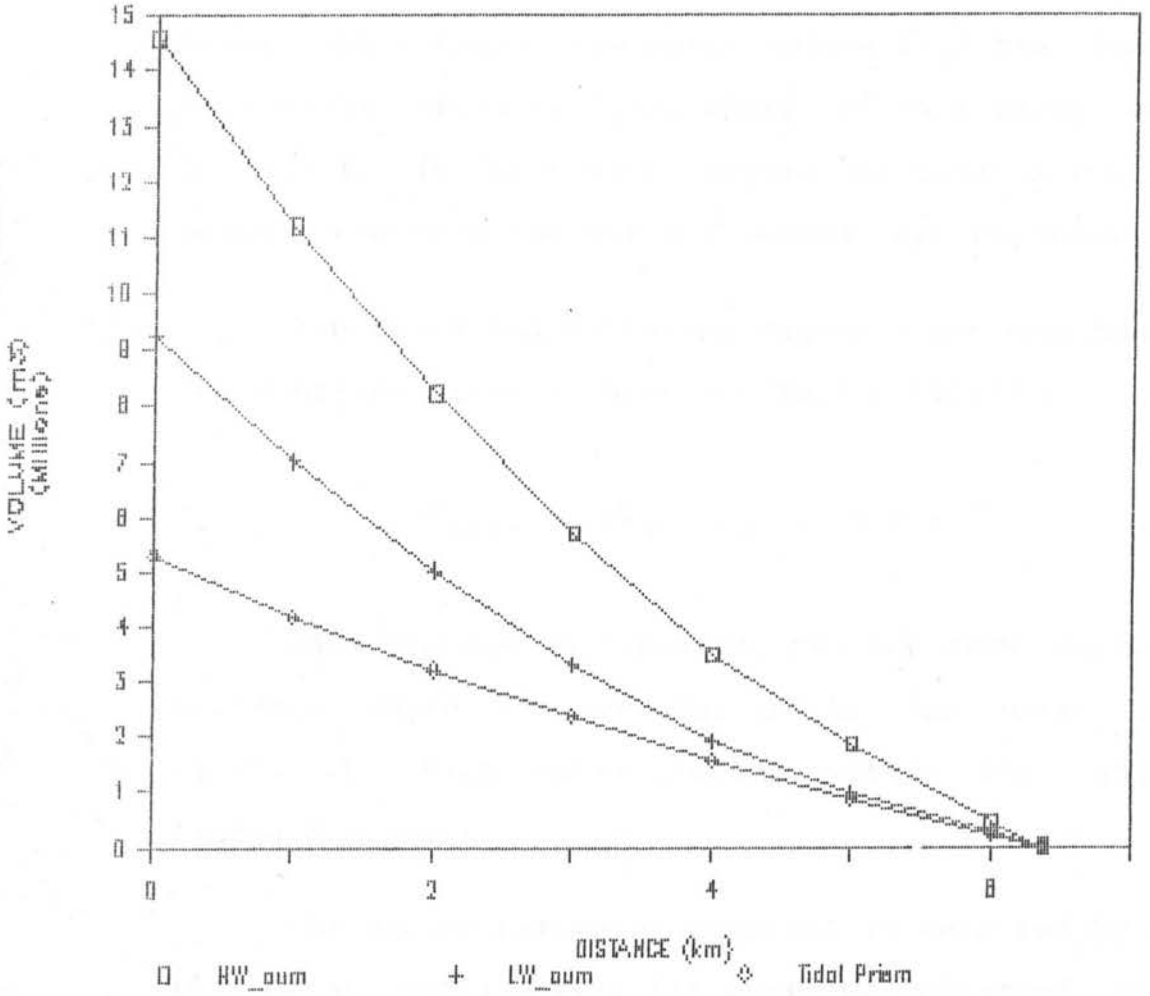
$$\text{Volume} = \frac{[\ A_{n+1} + A_n\ ]}{2} * \delta X \tag{3.5}$$

where A_n is cross section area at particular 'n' segment and δX is the different between the 'n'th segment and the next adjacent segment.

The sum of the volumes of water at high and low water enclosed by various cross sections was drawn and plotted against the length of the estuary, as in Figure 3.9. The volume of the tidal prism was computed using the model and is also plotted against the length of the estuary.

Determination of the segmentation of the estuary is illustrated below. The initial length distance is located at the upper-end of the estuary during low water

Figure 3.9 The cumulative volume of water at low and high water, and tidal prism enclosed by various cross sections (Example : Sg. Klang during spring tide).



where the boundary or interface between the salt water intrusion and river fresh water occurred. The distance at which the volume of low water (V_1) is equivalent to the river discharge per tidal cycle (R) is read from the graph, and for the same distance the tidal prism volume (P_1) is recorded.

The next adjacent segment is located at the point where the enclosed low water volume (V_2) has increased by a volume equal to P_1/a, where 'a' is a value between 0 and 1. The high water volume and tidal prism at a point, read from the various curves, are recorded.

The third and following segments are calculated by the equation given by Dyer and Taylor (1973) :

$$aV_{n+1} = aV_n + P_n \quad , \quad n > 2 \qquad (3.6)$$

This process is repeated, placing each successive boundary where the increase in the low water volume equals the high water volume within the adjacent landward segment.

The mixing parameter constant is selected by trial and error until a best fit curve was obtained to the observed data and then tested using Chi-square, χ^2, statistical analysis. Only the predicted curve which has no significant difference at 99% significant level was accepted.

Work was concentrated on running or executing the tidal prism model program in order to obtain a best fit model for each of the estuaries during both spring and neap tides, at high water and low water. This was done by varying the mixing parameter values. For the cases where the model prediction salinity values has significant different with the observed values by the X^2 test, an attempt was made to parameterise the mixing parameter by assuming that it varied in the form of a linear function. The linear equation used is as below :-

$$a = m(X/L) + C \qquad (3.7)$$

where a = mixing parameter

m = coefficient

X = location of segment volume

L = total estuary length

C = initial mixing parameter

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Estuary Behaviour

4.1.1 Survey Results

Surveys were conducted from September 1991 to January 1992. The physical condition such as river discharge, mean depth and width of the estuary, and tide range for all four estuaries are listed in Table 4.1. From the data, we can see that the river discharge for Sg. Langat and Sg. Klang are low, 31.1 m^3s^{-1} and 28 m^3s^{-1} respectively, as compared to either Sg. Selangor or Sg. Bernam discharge rate i.e. 53.5 m^3s^{-1} and 63.1 m^3s^{-1} respectively.

For the purpose of discussion, both Sg. Langat and Sg. Klang were categorised as *low river discharge* estuaries, and Sg. Selangor and Sg. Bernam categorised as *high river discharge* estuaries.

In order to classify the behaviour of the estuary for each condition, the form of salinity mixing diagrams were used (Figure 3.4). A particular location was selected, usually at the middle of the estuary, to represent the mixing patterns. The behaviour occurs was assumed to be similar along the estuary. The stratification mixing salinity diagram of Sg. Selangor

TABLE 4.1 PHYSICAL CONDIITIONS OF THE FOUR ESTUARIES.

ESTUARY OF	Q (M3/S)	R (M3/TC)	MEAN DEPTH (M)		TIDE RANGE (M)	
			NP	SP	NP	SP
SELANGOR	53.5	2406150	5.7	6.1	1.51	3.86
BERNAM	63.1	2838600	3.9	4.5	1.34	3.92
LANGAT	31.1	1399500	8.3	11.3	0.48	4.57
KLANG	28.0	1260000	8.5	9.4	1.46	3.66

TABLE 4.1 CONTINUE

ESTUARY OF	MEAN WIDTH (M)		TIDAL FLOW (M3/TC)	
	NP	SP	NP	SP
SELANGOR	442.6	593.8	5.8R	14R
BERNAM	886.0	902.7	10R	26R
LANGAT	228.6	257.0	1.5R	13R
KLANG	233.0	236.6	4.3R	9.9R

is shown in Figure 4.1, Sg. Bernam is shown in Figure 4.2, Sg. Klang in Figure 4.3 and Sg. Langat is shown in Figure 4.4.

The difference of salinity ratio in the mixing profile diagrams was used for the determination of estuary's behaviour. The three general types of mixing in estuary i.e. well mixed, partially mixed and highly stratified (Dyer, 1973) was divided into five section according to the range of salinity ratio as listed in Table 4.2 .

Table 4.2 Classification of the behaviour of estuary by difference of salinity ratio. (from Table 3.2, section 3.3.1).

Diff. sal. ratio	Mixing Pattern
≤ 0.20	Well Mixed (WM)
0.21 - 0.40	Slightly Partially Mixed (SPM)
0.41 - 1.00	Partially Mixed (PM)
1.01 - 1.20	Slight Highly Stratified (SHS)
> 1.20	Highly Stratified (HS)

The classification of the four estuaries (Figure 4.1 to 4.4) by using the difference of salinity ratio was summarised in Table 4.3.

The results of all the sampling data were transferred onto diagrams showing the isohaline along the estuaries. The isohaline graphs were plotted for

Figure 4.1 Salinity mixing ratio diagram for Sg. Selangor at different tide conditions.

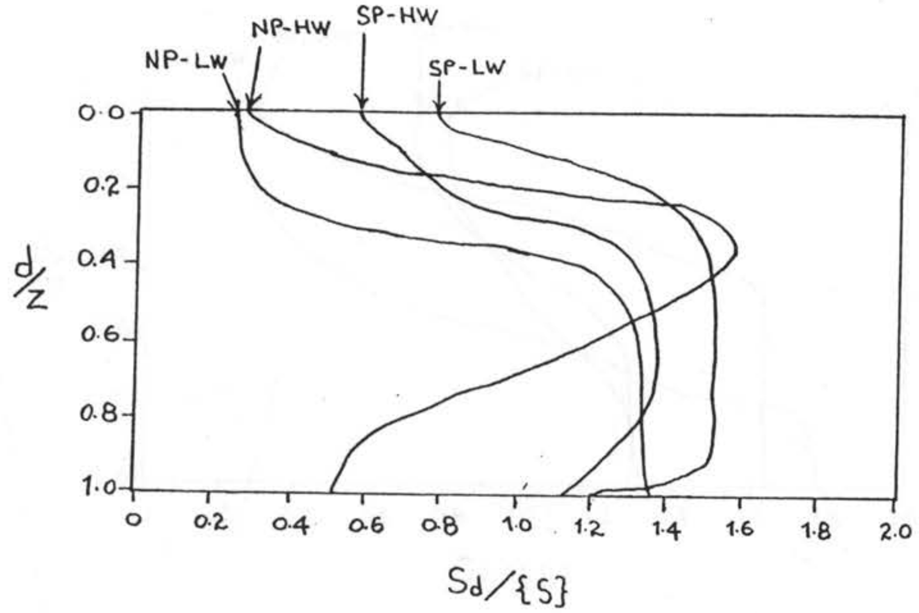


Figure 4.2 Salinity mixing ratio diagram for Sg.Bernam at different tide conditions.

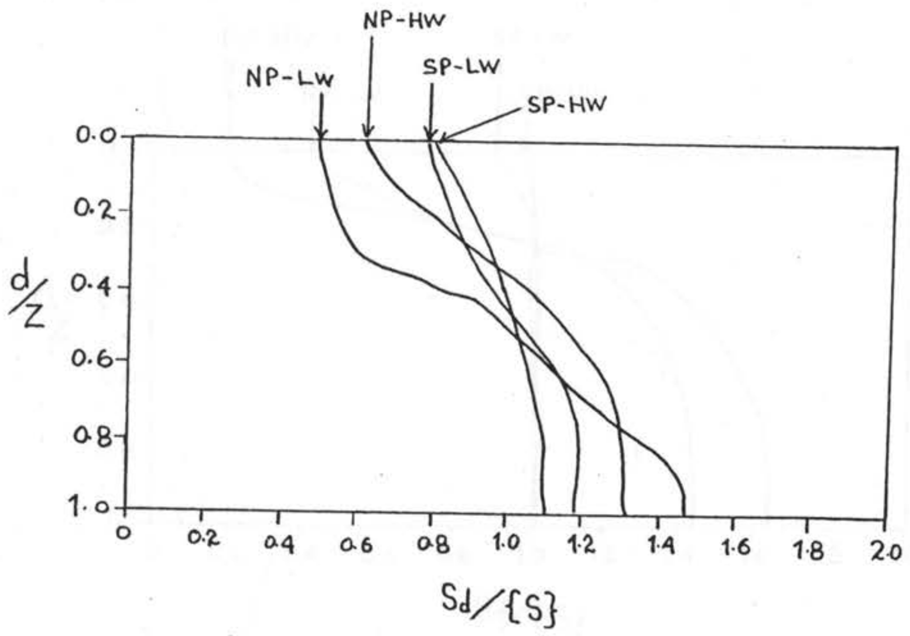


Figure 4.3 Salinity mixing ratio diagram for Sg.Klang at different tide conditions.

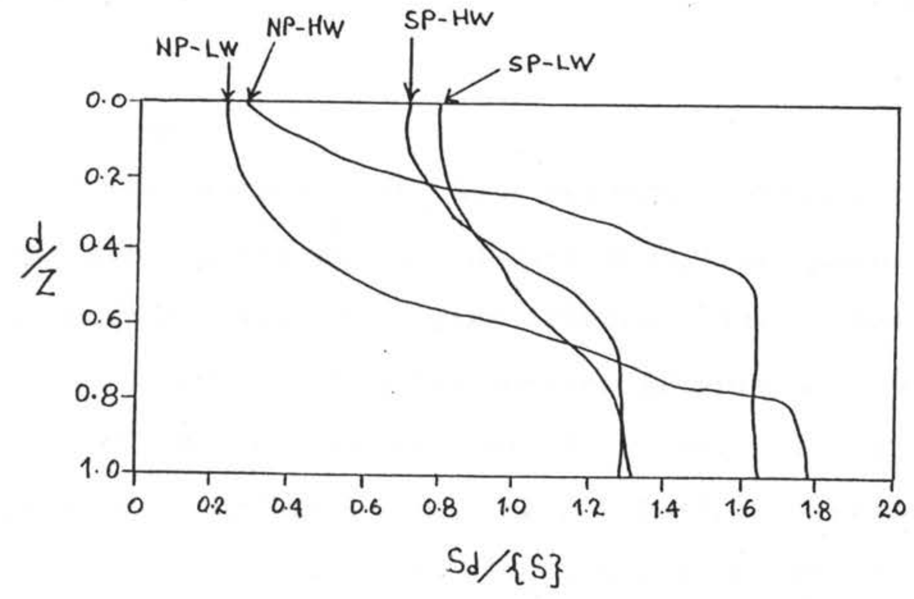
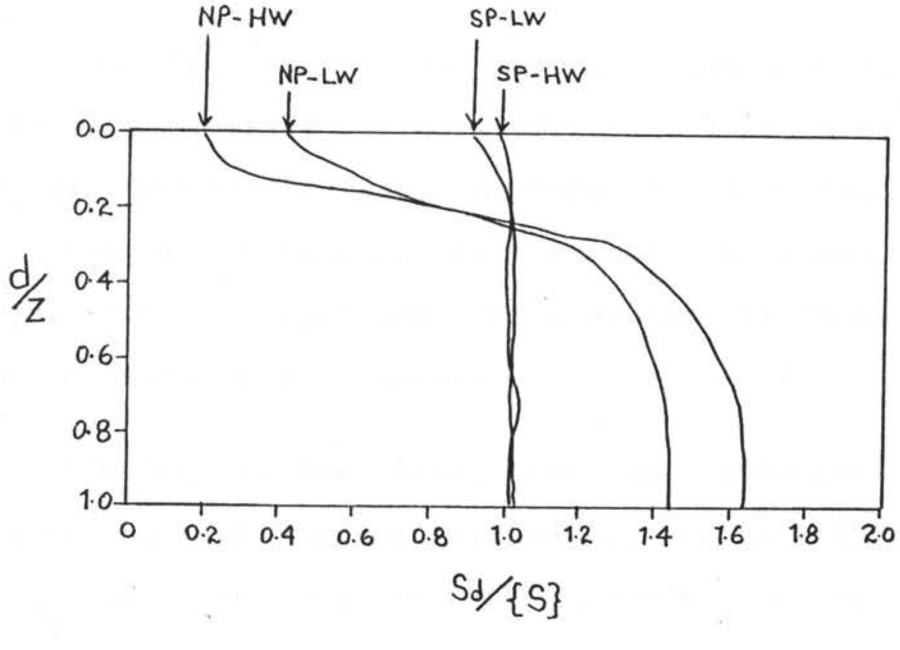


Figure 4.4 Salinity mixing ratio diagram for Sg.Langat at different tide conditions.



both spring and neap tide during high water and low water conditions. These graphs are shown in Figure 4.5 to 4.20.

Sg. Selangor

The estuary of Sg. Selangor overall shows a partially mixed estuary during neap tide according to the mixing salinity diagram (Figure 4.1). A salt wedge occurs at 40% depth below surface (Figure 4.1) while the rest of depth are well mixed. There is a reduced salinity concentration near bottom area. This occurrence may be due to undulating river bed which caused water trapped in the "pockets". When seawater coming into the estuary, the trapped water will mixed within and altered the original salt concentration thus resulting a curve as shown in Figure 4.5 and 4.6.

At low water, Sg. Selangor changed to slight highly stratified estuary (Figure 4.1 & 4.6). This change may due to less tide range and low velocity of seawater intrusion where less turbulence occurs. Hence, owing to the higher dense of seawater, it flows at the bottom layer of the estuary.

During spring tide, the Sg. Selangor estuary behaves partially mixed (Figure 4.1) in both high water (Figure 4.7) and low water (Figure 4.8). At this volume rate of seawater enter the estuary causing quite turbulence. Furthermore the depth is about 6.1m and the

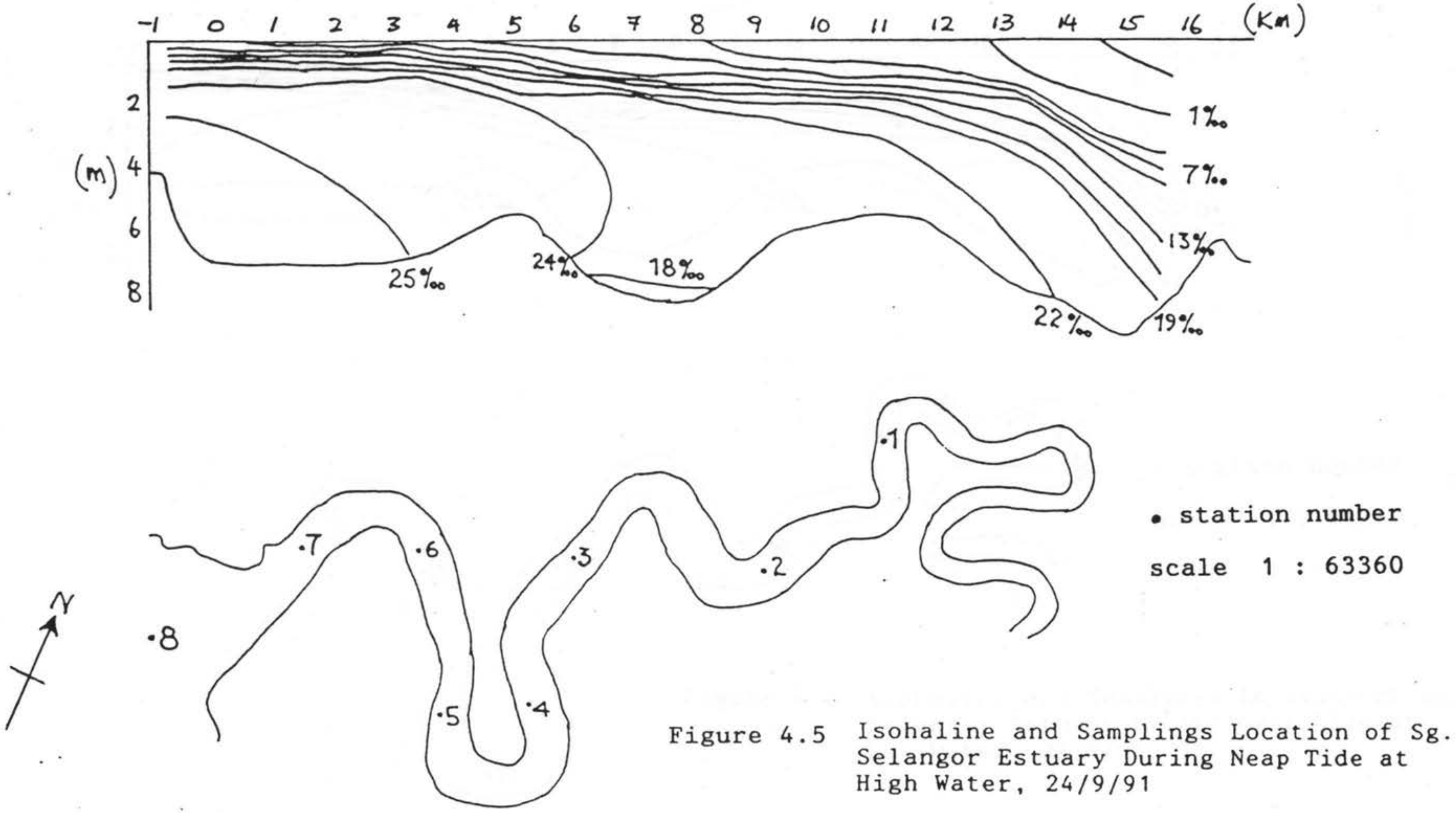


Figure 4.5 Isohaline and Samplings Location of Sg. Selangor Estuary During Neap Tide at High Water, 24/9/91

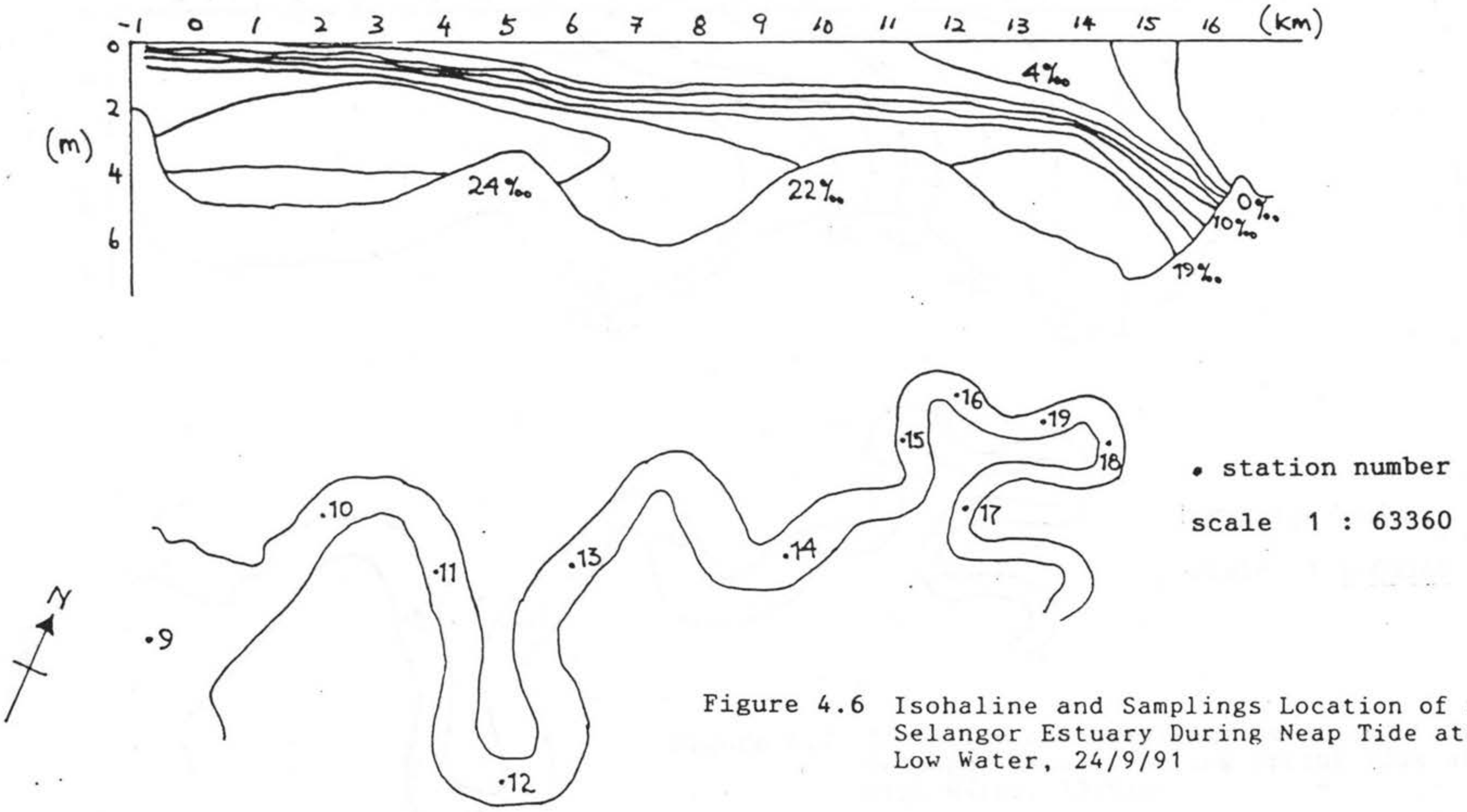


Figure 4.6 Isohaline and Samplings Location of Sg. Selangor Estuary During Neap Tide at Low Water, 24/9/91

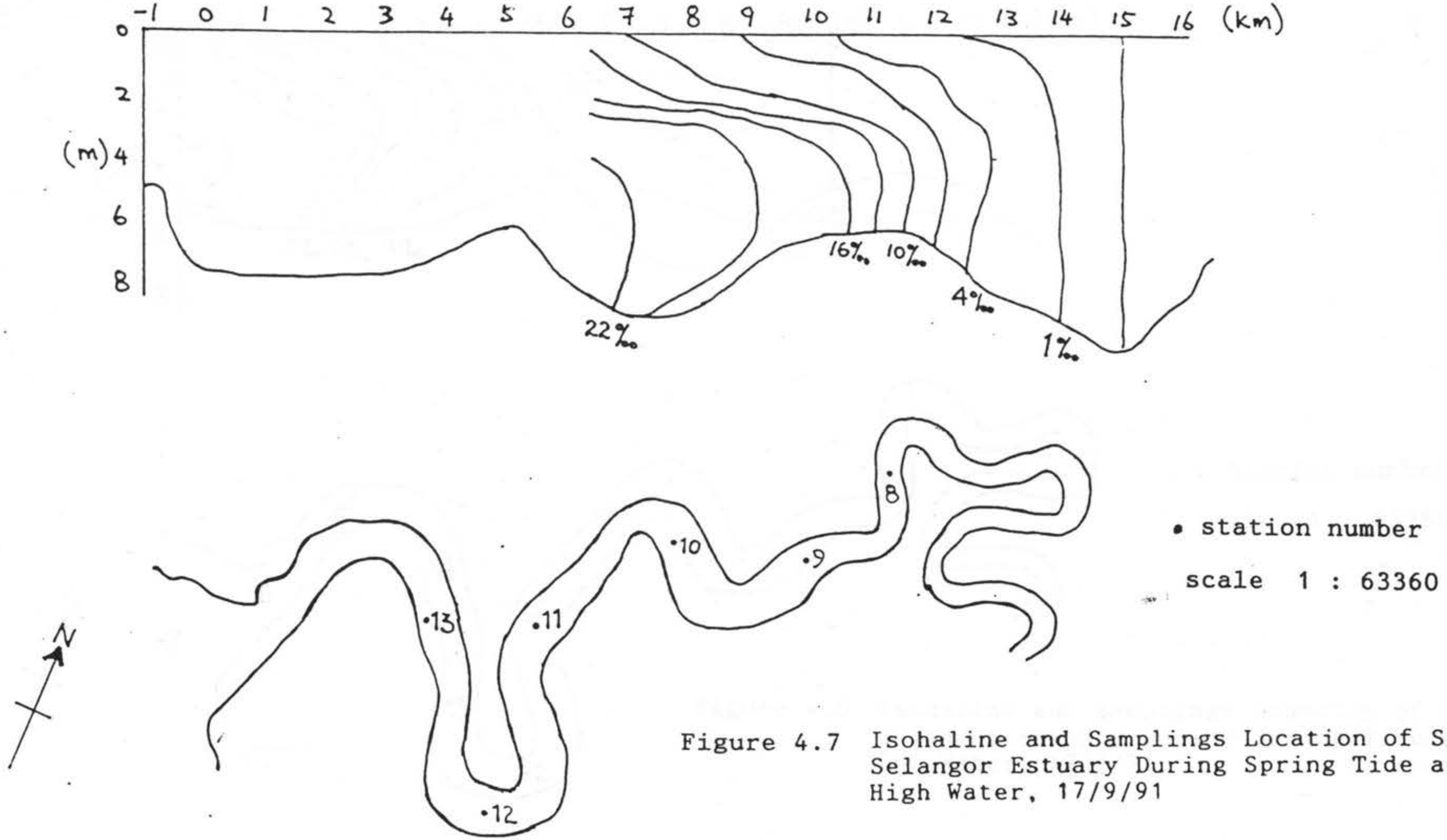


Figure 4.7 Isohaline and Samplings Location of Sg. Selangor Estuary During Spring Tide at High Water, 17/9/91

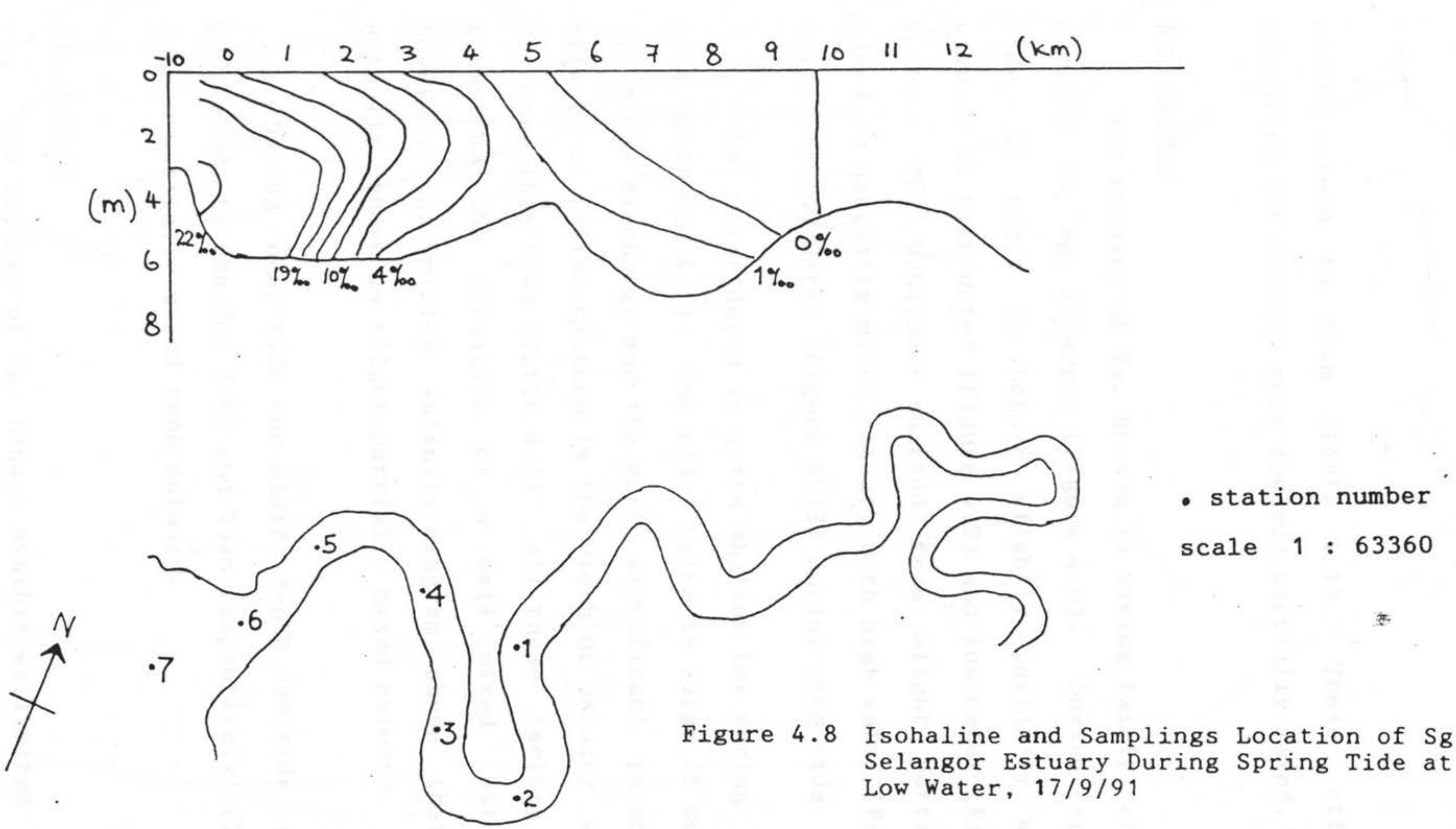


Figure 4.8 Isohaline and Samplings Location of Sg. Selangor Estuary During Spring Tide at Low Water, 17/9/91

width extend to 594m (Table 4.1). These effects promoting the estuary more towards partially mixed.

Sg. Bernam

The estuary of Sg. Bernam is having fairly change compare to Sg. Selangor (Figure 4.2). During spring tide, it tends to behave slightly partially mixed estuary at high water (Figure 4.9) and low water (Figure 4.10). The behaviour shifted from slight partially mixed to partially mixed estuary both high water (Figure 4.11) and low water (Figure 4.12) during neap tide.

The water depth is quite shallow for spring tide at 4.5m (Table 4.1). The tidal prism is large if compare to river discharge and the most significant potential effect of mixing pattern is the width of estuary which is more than 900m (Table 4.1). All these factors are promoting the formation of a well mixed estuary. however, the mixing salinity diagram shows that it actually behave as slight partially mixed estuary.

During neap tide the width, depth and tide range decreased to 886.0m, 3.9m and 134m respectively (Table make a partially mixed type estuary.

Sg. Langat

The estuary of Sg. Langat exhibit well mixed type during spring tide (Figure 4.3) for both high water

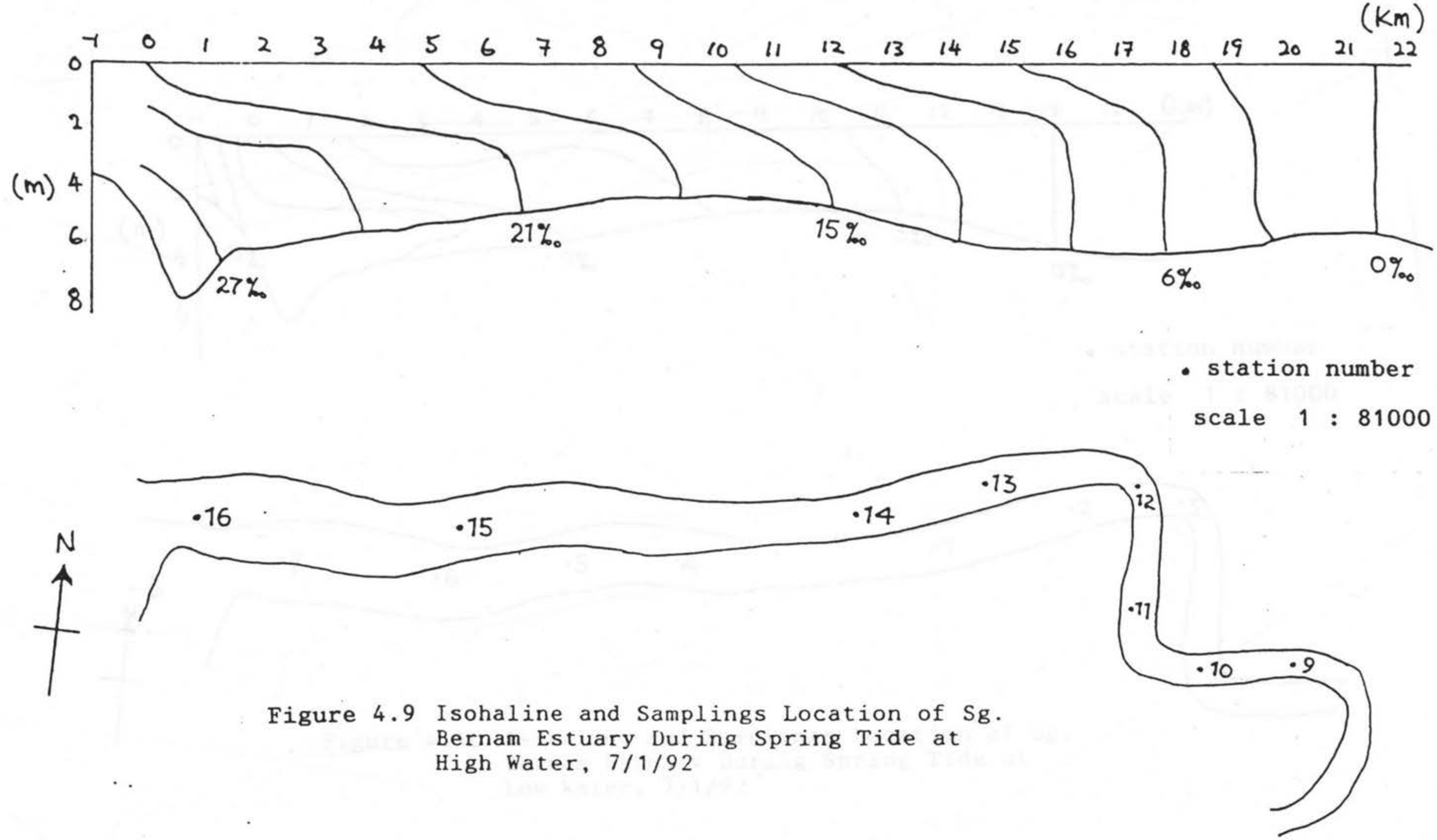


Figure 4.9 Isohaline and Samplings Location of Sg. Bernam Estuary During Spring Tide at High Water, 7/1/92

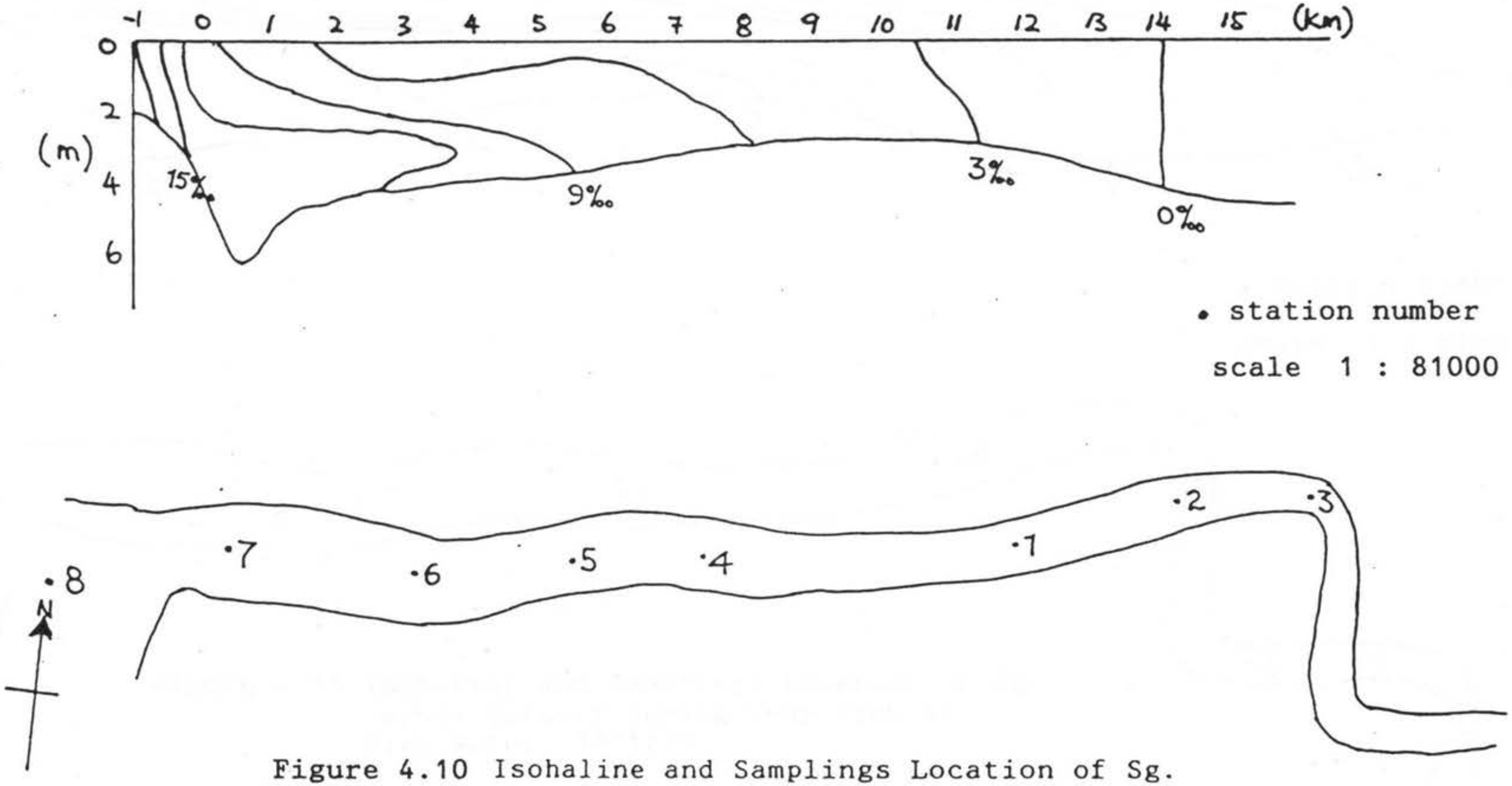


Figure 4.10 Isohaline and Samplings Location of Sg. Bernam Estuary During Spring Tide at Low Water, 7/1/92

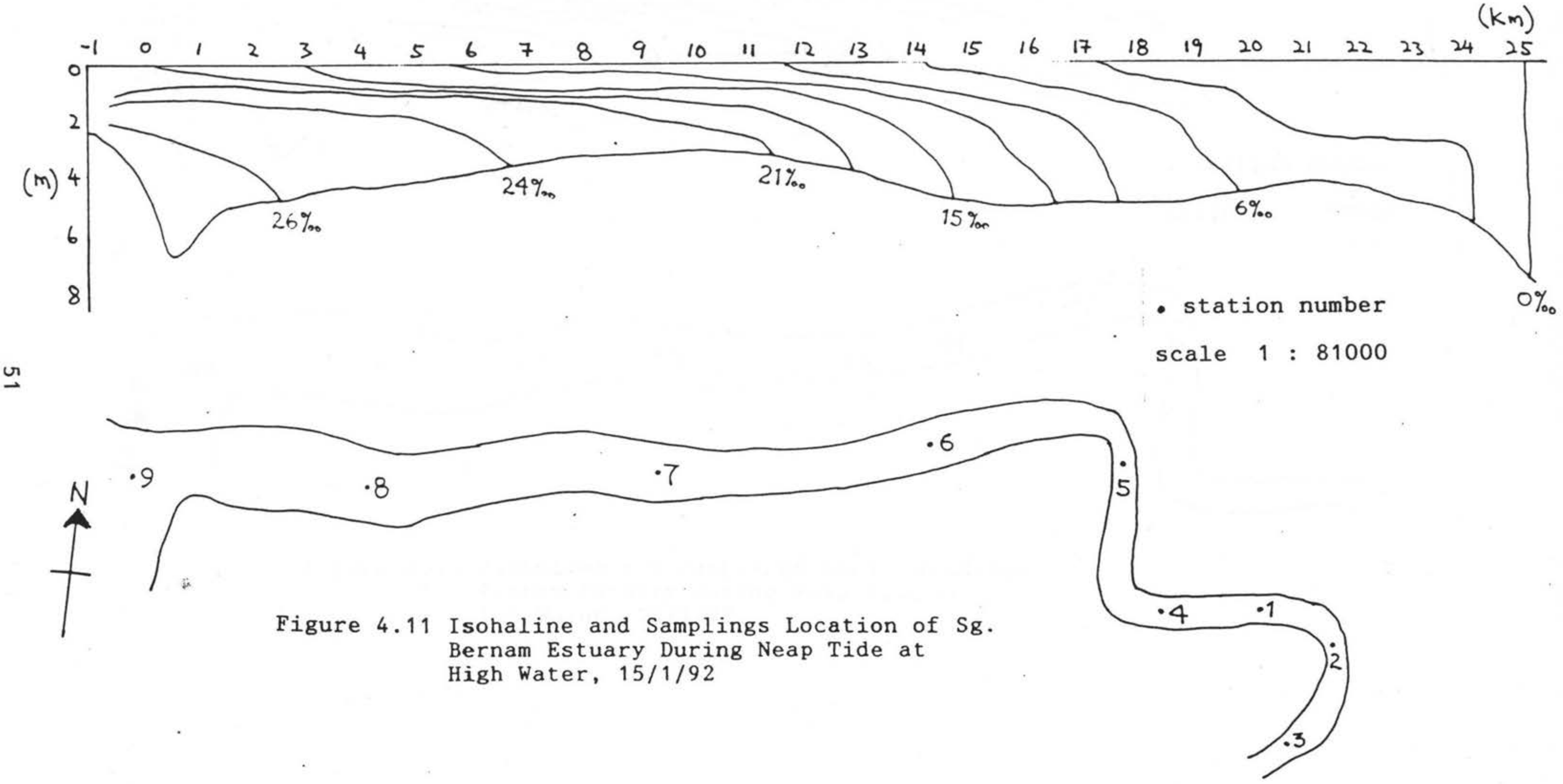


Figure 4.11 Isohaline and Samplings Location of Sg. Bernam Estuary During Neap Tide at High Water, 15/1/92

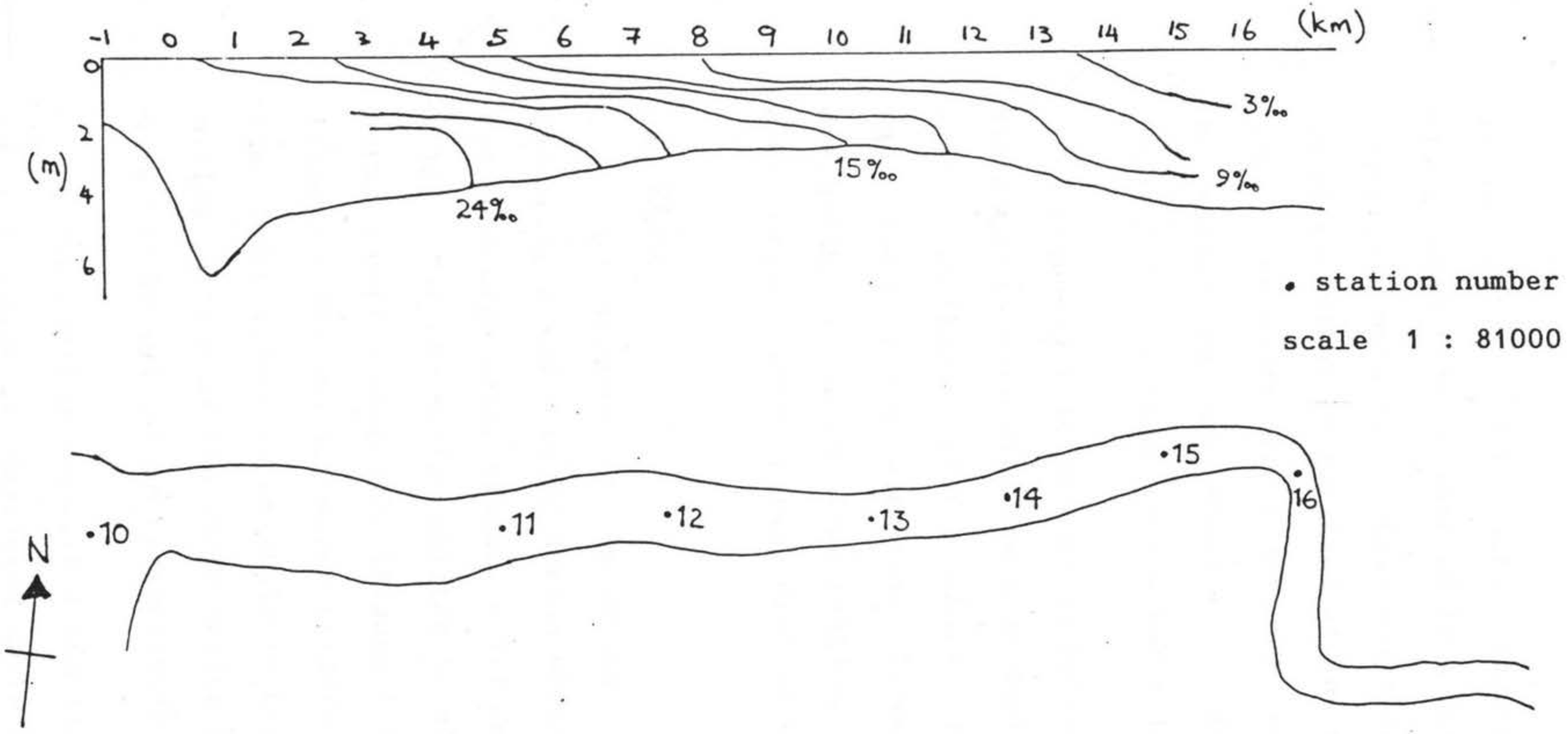


Figure 4.12 Isohaline and Samplings Location of Sg. Bernam Estuary During Neap Tide at Low Water, 15/1/92

(Figure 4.13) and low water (Figure 4.14). Contrary during neap tide it shifted from well mixed to highly stratified estuary at high water (Figure 4.3 & 4.15) and slight highly stratified at low water (Figure 4.3 & 4.16). The width effect does not seems to contribute to the mixing pattern where it is about 257m and 233m (Table 4.1) for high and low water respectively.

Although this estuary is categorised as low river discharge estuary with the mean depth of 11.3m but still well mixed characteristic occurs. This is mainly due to the tidal prism was very large compare to river discharge, R (mean tide range of 4.57m) and it is dominant over other parameters' effects.

Sg. Klang

The estuary of Sg. Klang tends to behave as partially mixed estuary during spring tide (Figure 4.4) for both high water (Figure 4.17) and low water (Figure 4.18). But the system shifted to highly stratified type estuary during neap tide (Figure 4.4) at also high water (Figure 4.19) and low water (Figure 4.20). In this case the width effect is unlikely to have influence on the mixing pattern as the width during neap and spring tide were 233.0m and 236.6m respectively.

The tidal prism with 3.66m (Table 4.1) difference in tide range is considered quite large if compare to river discharge, R and thus it should have behave like a

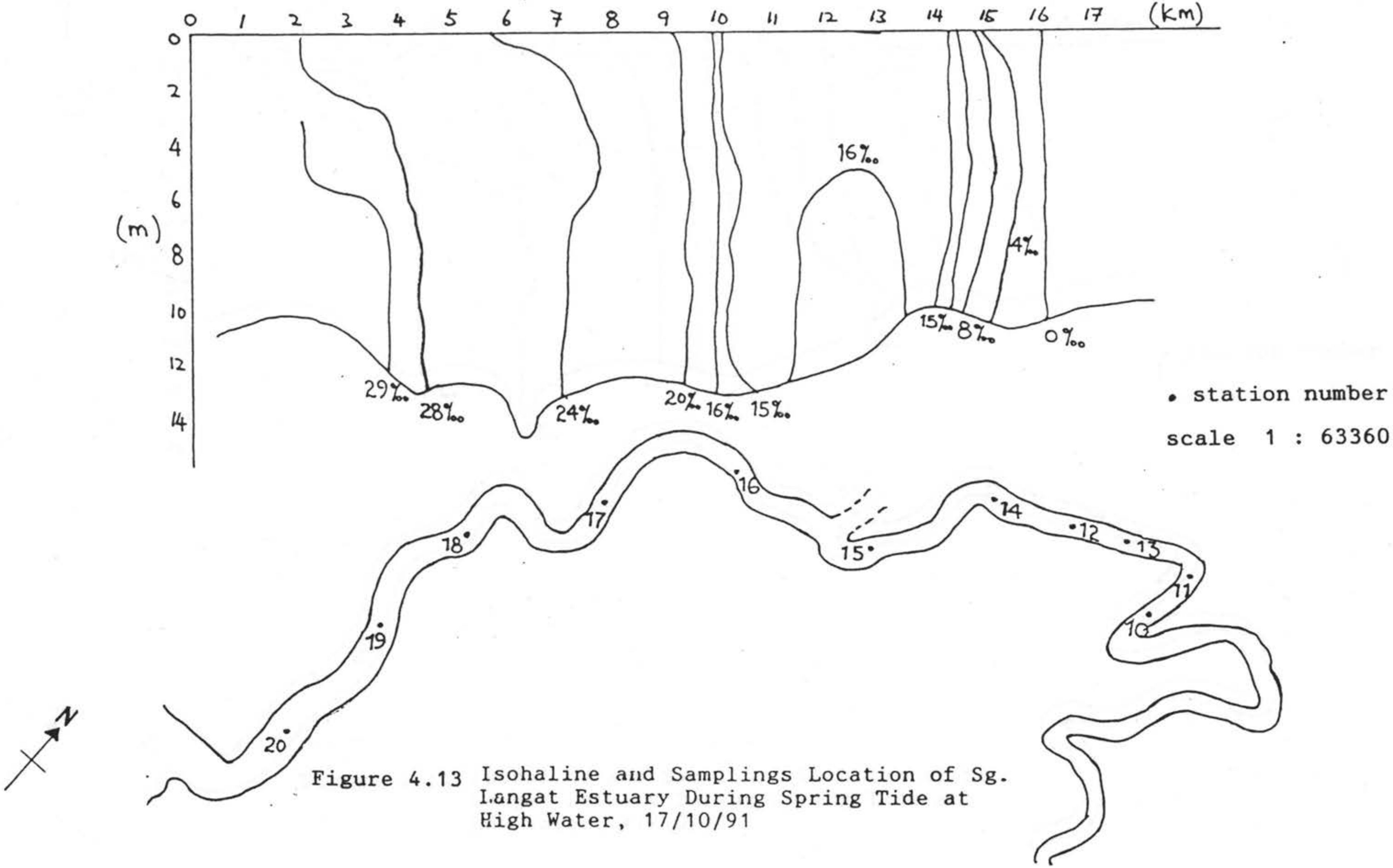


Figure 4.13 Isohaline and Samplings Location of Sg. Langat Estuary During Spring Tide at High Water, 17/10/91

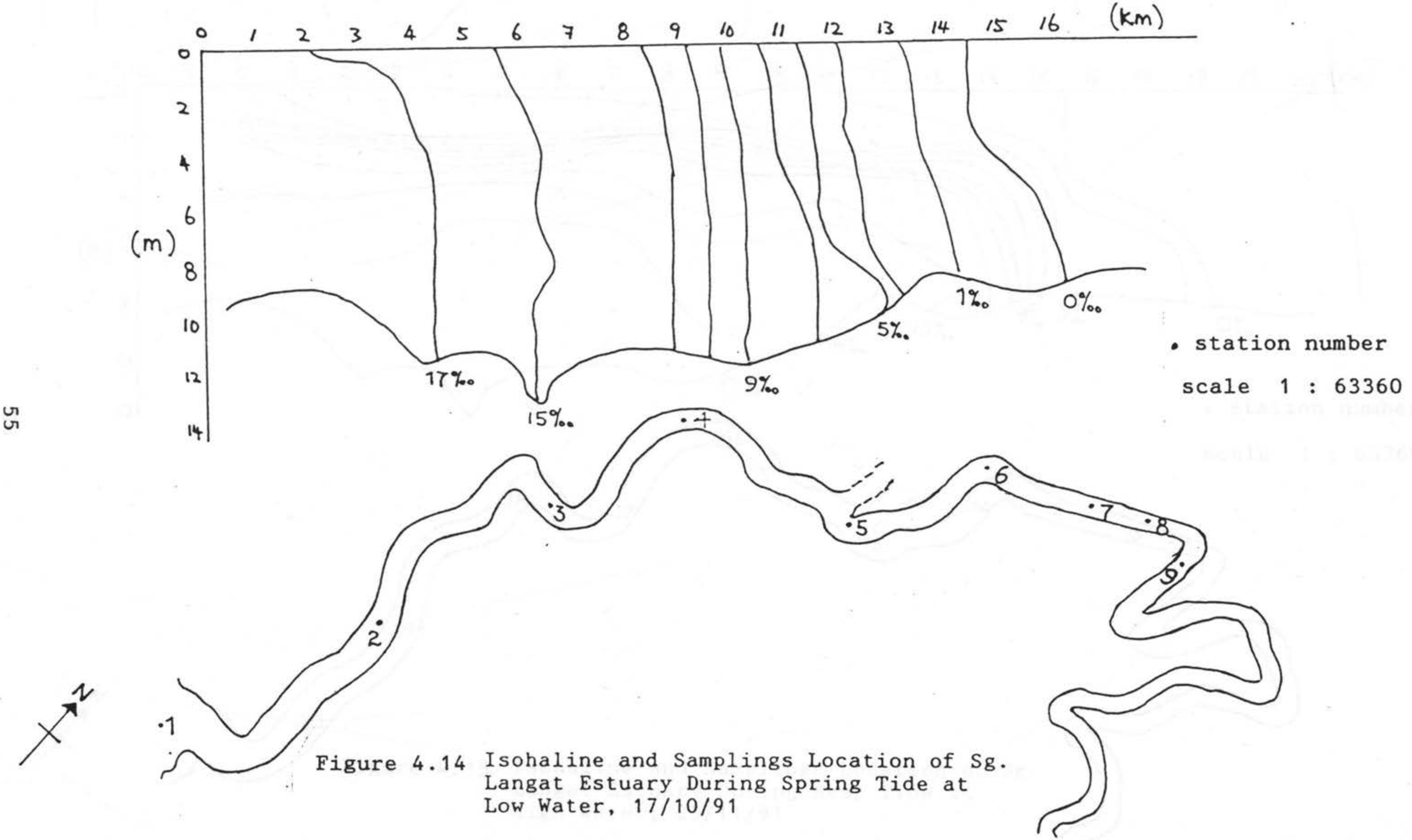


Figure 4.14 Isohaline and Samplings Location of Sg. Langat Estuary During Spring Tide at Low Water, 17/10/91

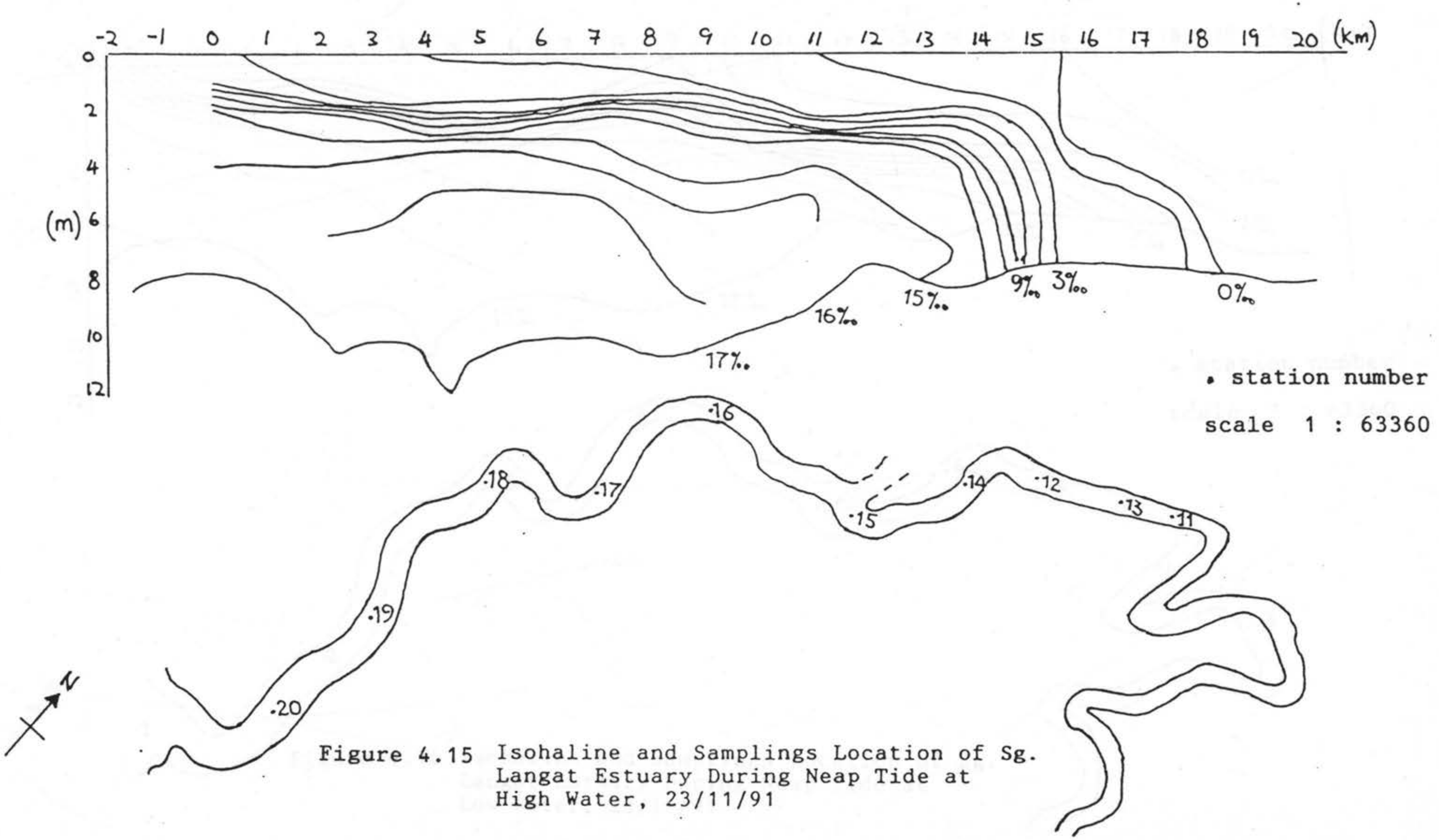


Figure 4.15 Isohaline and Samplings Location of Sg. Langat Estuary During Neap Tide at High Water, 23/11/91

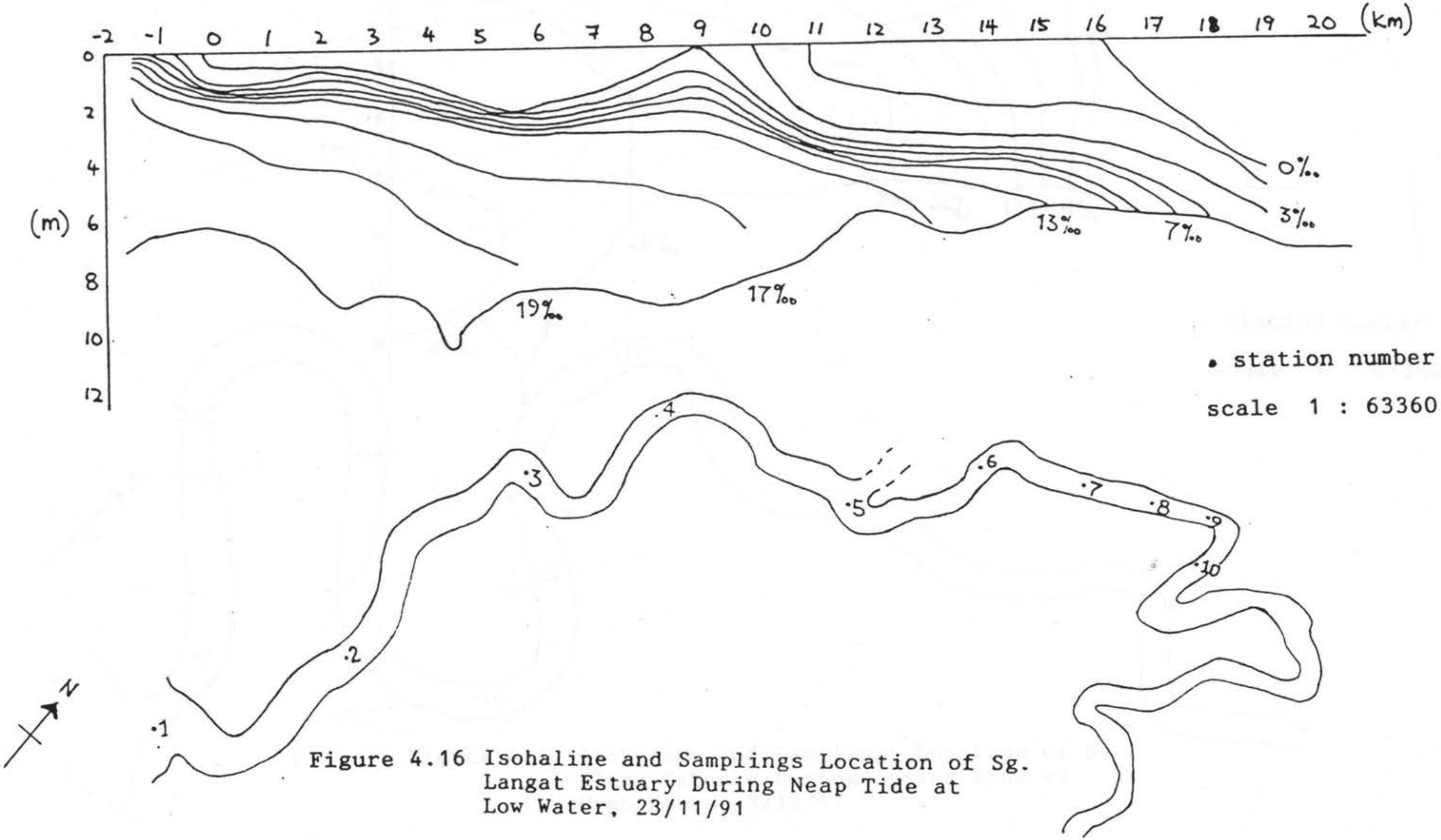


Figure 4.16 Isohaline and Samplings Location of Sg. Langat Estuary During Neap Tide at Low Water, 23/11/91

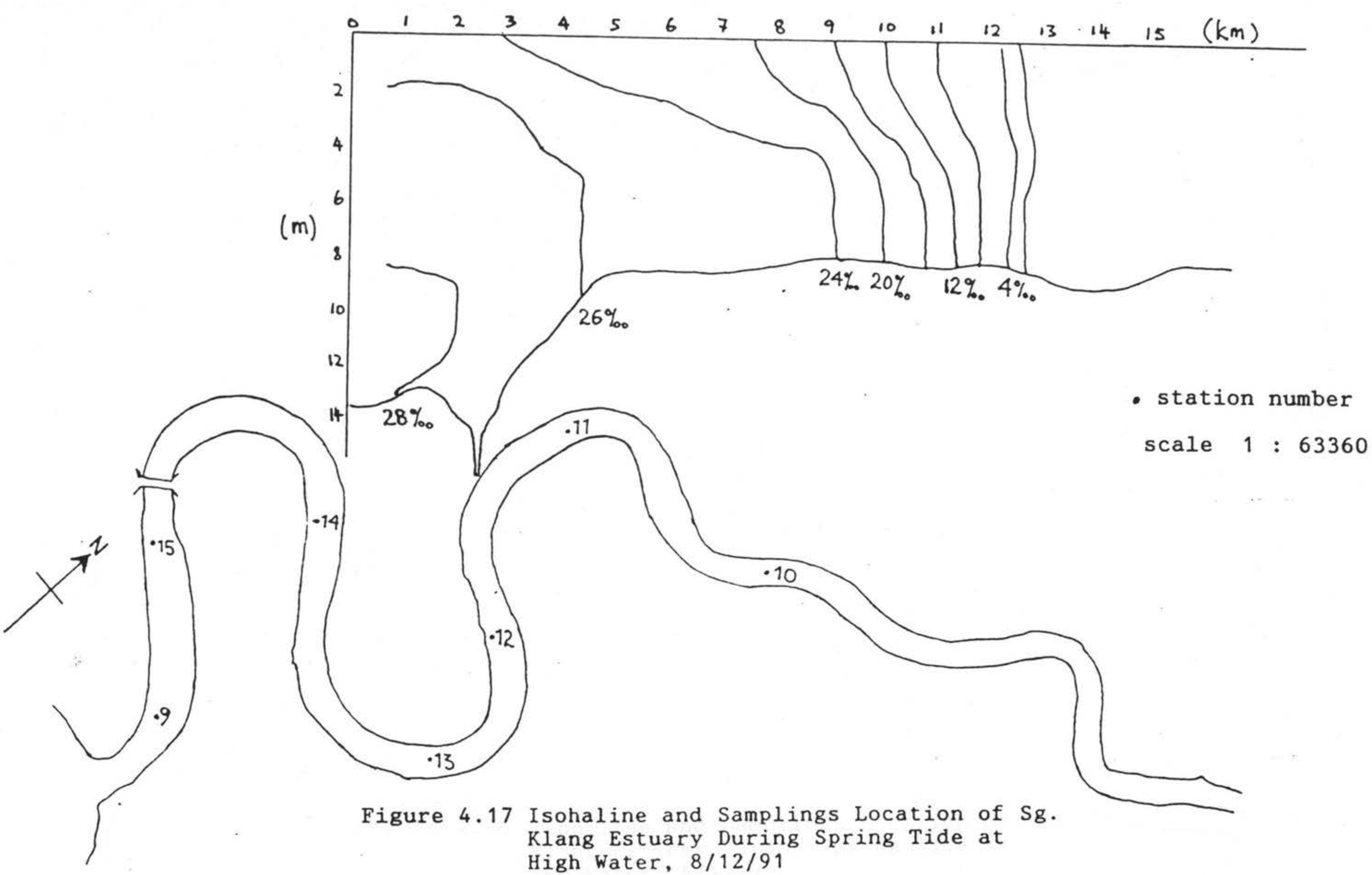


Figure 4.17 Isohaline and Samplings Location of Sg. Klang Estuary During Spring Tide at High Water, 8/12/91

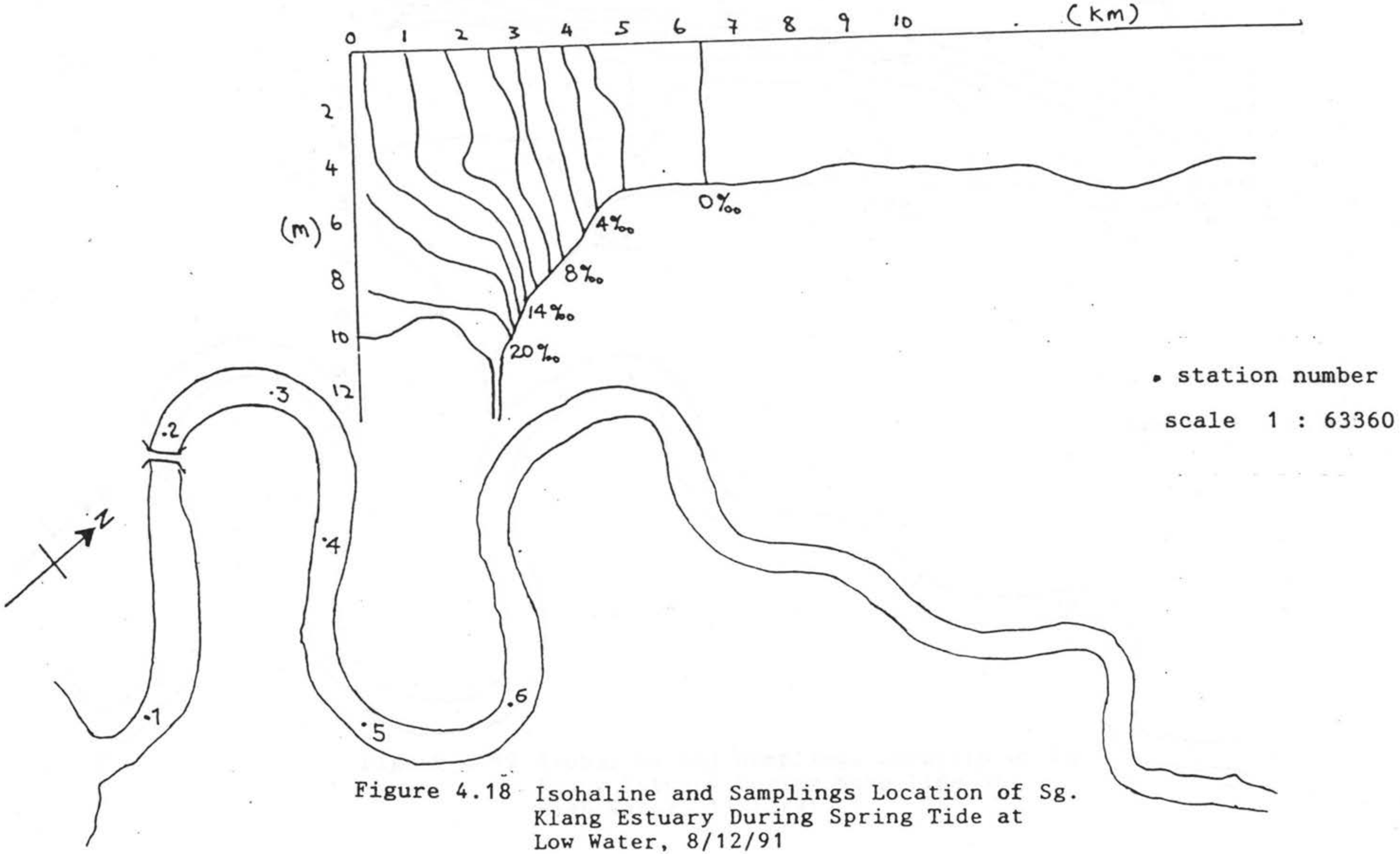


Figure 4.18 Isohaline and Samplings Location of Sg. Klang Estuary During Spring Tide at Low Water, 8/12/91

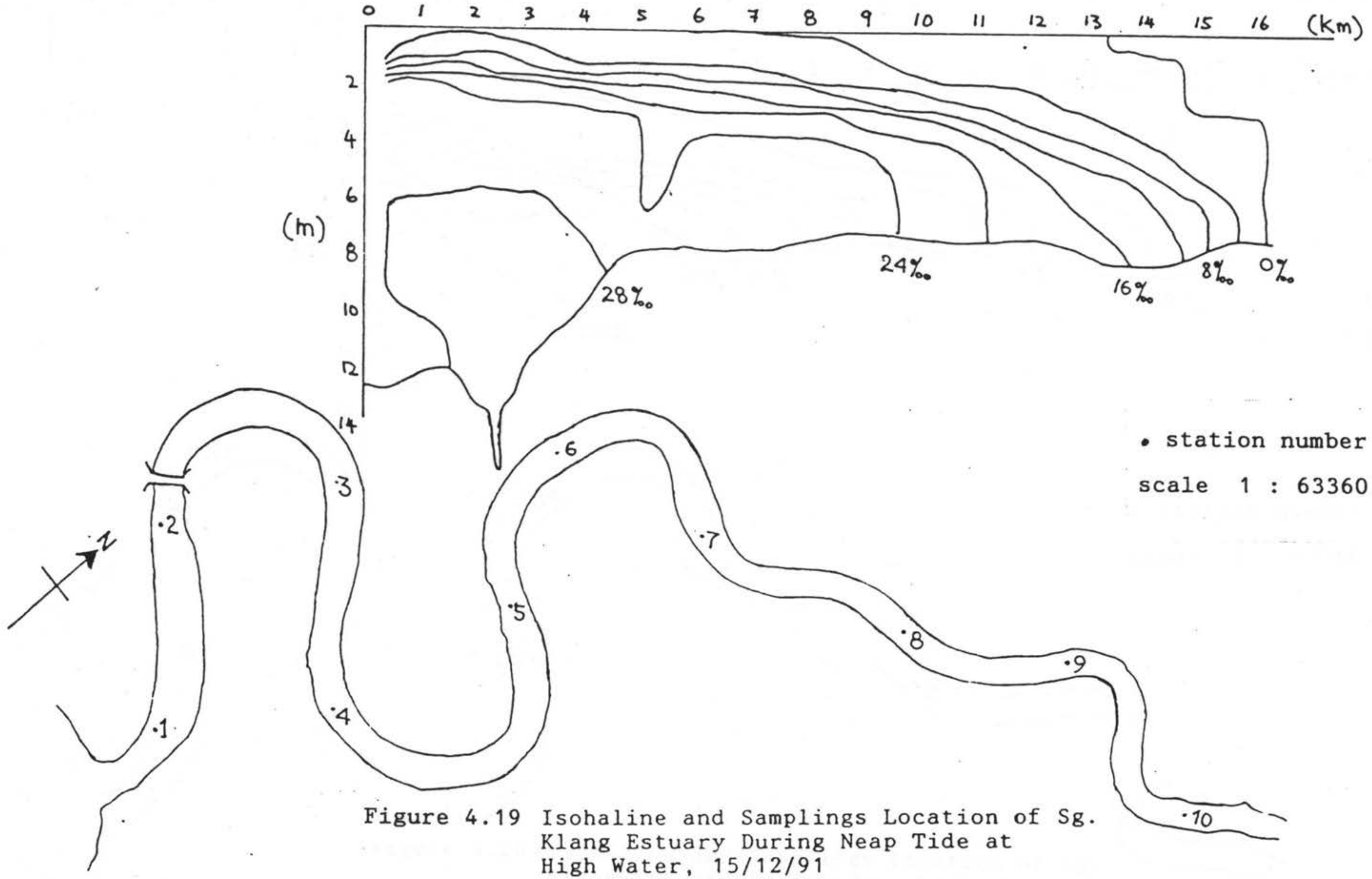


Figure 4.19 Isohaline and Samplings Location of Sg. Klang Estuary During Neap Tide at High Water, 15/12/91

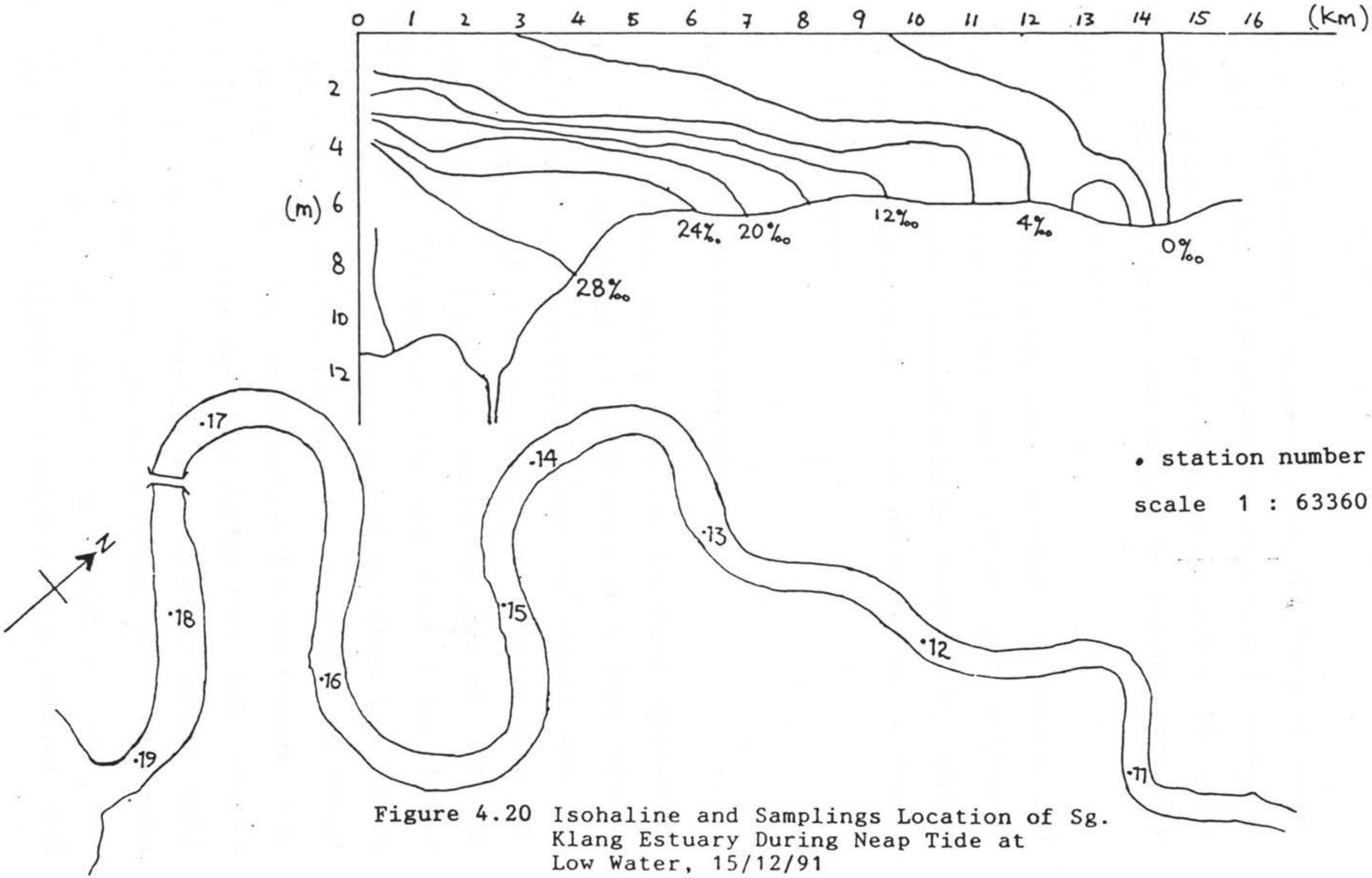


Figure 4.20 Isohaline and Samplings Location of Sg. Klang Estuary During Neap Tide at Low Water, 15/12/91

well mixed estuary. However, since the depth of water column is also large (9.4m) (Table 4.1) and tends to lower down the vertical mixing. As a result of these two combine effects, the estuary is having partially mixed characteristic.

During neap tide, the tide range difference and the mean depth of the water column are decreased. Therefore these combined effects forced the estuary behave towards more stratified and resulting a highly stratified estuary.

4.1.2 Low River Discharge Estuary

As for the case of low river discharge estuaries, the river discharge and width are more or less similar for spring and neap tides between Sg. Langat and Sg. Klang. Thus, the river discharge and width for both Sg. Langat and Sg. Klang were considered constant all the time. During spring tide, the mean depth of Sg. Langat is greater than the mean depth of Sg. Klang i.e. 11.3m and 9.4m respectively (Table 4.1). Visually, Sg. Langat during spring tide showed more well mixed (Figure 4.3, 4.13 & 4.14) than Sg. Klang during same tide (Figure 4.4, 4.17 & 4.18). This is due to another factor which is dominating over the depth effect i.e. the tidal prism. The tidal prism of Sg. Langat is very much larger ($\simeq$13R) (Table 4.1) and therefore causing well mixed estuary according to Pritchard and Carter's proposal (1971). Whereas the effect of tidal prism on Sg. Klang is less ($\simeq$10R) (Table 4.1) and combined with the depth effect makes it tends to behave partially mixed.

During neap tide both tidal prism of Sg. Langat and Sg. Klang reduced to 1.5R and 4.3R respectively. Hence, the tidal prism effect is less contribute in determining of the estuary behaviour. The depth effect now prevailing and since the depth are both > 8.0m (Table 4.1) (compare to the depth of all four estuaries is relatively deep), it results in lowering the effectiveness of tidal velocity promoting vertical mixing, and further due to the difference in density of salt water and fresh water, eventually the estuary system tends to behave as highly stratified estuary.

4.1.3 High River Discharge Estuary

The high river discharge estuaries i.e Sg. Selangor and Sg. Bernam which the factors influenced the mixing pattern are differ from those estuaries of low river discharge estuaries. The river discharge and the tide range are about the same during spring and neap tide for both estuaries. However, the length of seawater intrusion is not proportion to the tide range and therefore resulting in different tidal prisms. By comparing the width and depth of both estuaries, apparently the width effect will dominate in determining the mixing pattern. There is no doubt that during spring tide Sg. Bernam tends towards well mixed estuary due to the over 900m estuary width, tidal prism up to 26R and a shallow mean depth ($\leq$ 4.5m) (Table 4.1).

A partially mixed estuary was detected during spring tide for Sg. Selangor (Figure 4.1). As compare to Sg. Bernam, the width and tidal prism are about half of Sg. Bernam's values i.e 593.8m and 14R respectively but the depth is greater (6.1m) (Table 4.1). The effect of width promoting the estuary towards well mixed but in contrast the tidal prism and depth effects promoting towards highly stratified. As a result the estuary tends to behave in a partially mixed type of mixing.

During neap tide there is a large fall in tidal prism from 14R to 5.8R and the width decreased approximately 150m to 442.6m but only a slight change in depth (5.7m) (Table 4.1). All these combined condition resulted a net that promote towards the formation of highly stratified estuary.

In short, the increment in river discharge does not mean that the estuary will behave towards highly stratified or vice versa. There also occurred slightly partially mixed estuary with high river discharge, for instance Sg. Bernam during spring tide (Figure 4.9 &

4.10) and highly stratified estuary with low river discharge like Sg. Langat also at neap tide (Figure 4.15 & 4.16) and Sg. Klang at neap tide (Figure 4.19 & 4.20).

The formation of estuary behaviour or mixing patterns are greatly influenced by local physical parameters conditions i.e. tidal prism, width and depth of estuary, and tidal velocity (which is discounted in discussion of this project study).

4.1.4 Implications

By knowing the behaviour of the estuary for several conditions, we can assess the pollutant concentrations which are associated with the mixing processes. In a highly stratified estuary, the pollutants will tend to concentrate in the fresh water layer more than in the salt water layer. This situation is likely to occurs in Sg. Klang and Sg. Langat during neap tide. For a well mixed estuary the situation is different where the pollutants will be well distributed from surface to the bottom of the estuary. This is likely to occurs in Sg. Langat during spring tide.

This implies that in a similar length of estuary, the pollutants in a highly stratified estuary will caused more damage to the surface aquatic organisms such as phytoplankton and the organisms which live along the mudflats. But the benthic groups in the bottom of the estuary would be free from the pollutants' threats.

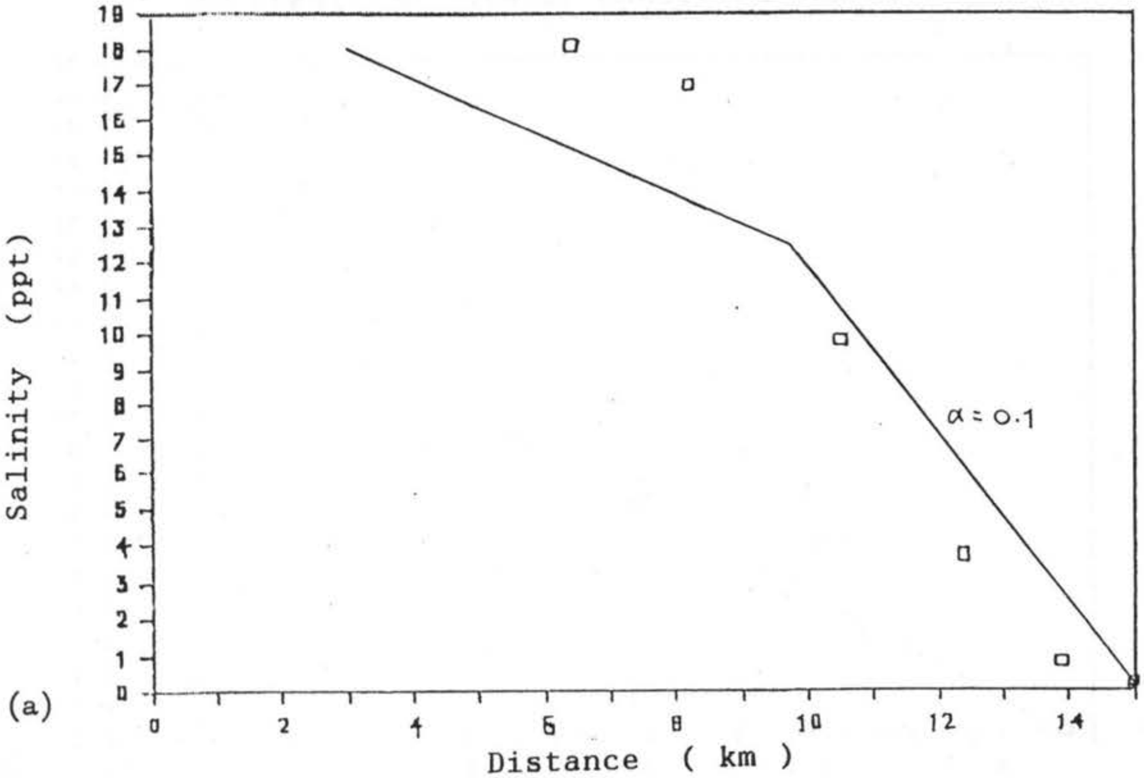
In a well mixed estuary the pollutant effects will be "diluted"; but if the concentration of the pollutants were very high, even though it is diluted, it would affect both the surface and bottom living aquatic organisms and plants.

4.2 Box Models

Overall the estuaries were well predicted by the simple segmented tidal prism model (Table 4.4). The best fitting model curves are compared to the observed data for the Sg. Selangor estuary for four tide conditions is shown in Figures 4.21 to 4.24, Sg. Bernam is shown in Figure 4.25 to 4.28, Sg. Langat in Figure 4.29 to 4.32 and Sg. Klang is shown in Figure 4.33 to 4.36. The symbols (□) are the observed data. The best mixing parameter value is not similar for all the estuaries although sometimes the value is the same for different tide conditions (Table 4.4). For instance, Sg. Selangor has the same mixing parameter value (a=0.1) during spring tide at high and low water.

By setting a 99% significant level in the χ^2 test, 13 out of 16 tide conditions for the four estuaries showed no difference between observed and predicted values. It indicates that these conditions were well

Figure 4.21a Comparison Between Observed Data and
&b Predicted Data of Condition SEL-SP-HW



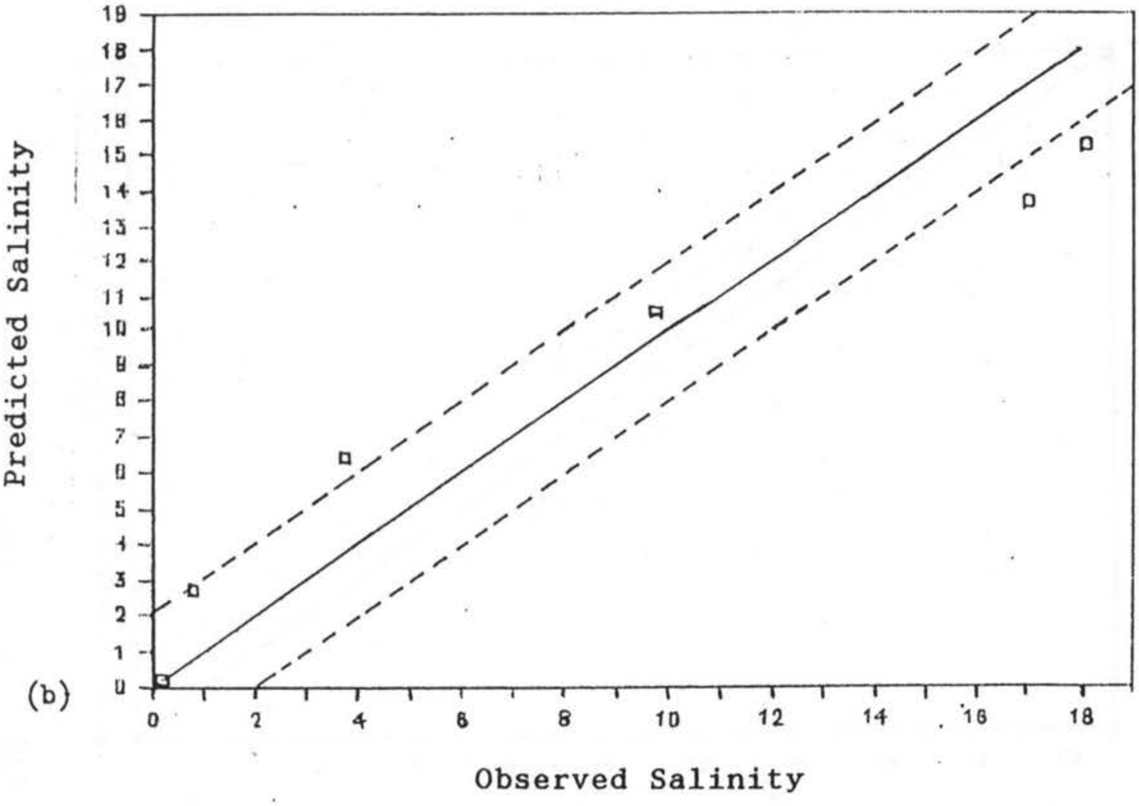


Figure 4.22a Comparison Between Observed Data and
&b Predicted Data of Condition SEL-SP-LW

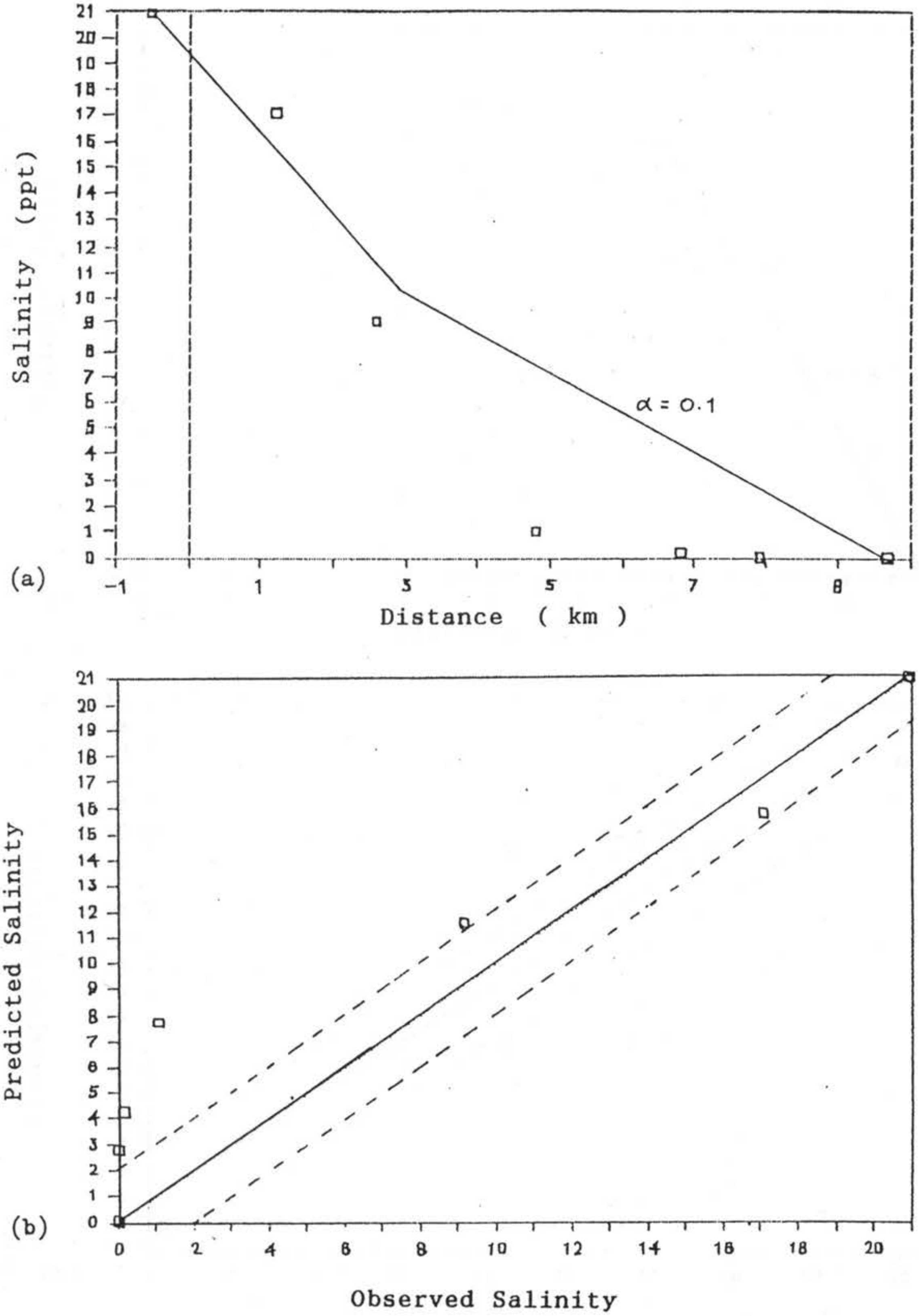


Figure 4.23a &b Comparison Between Observed Data and Predicted Data of Condition SEL-NP-HW

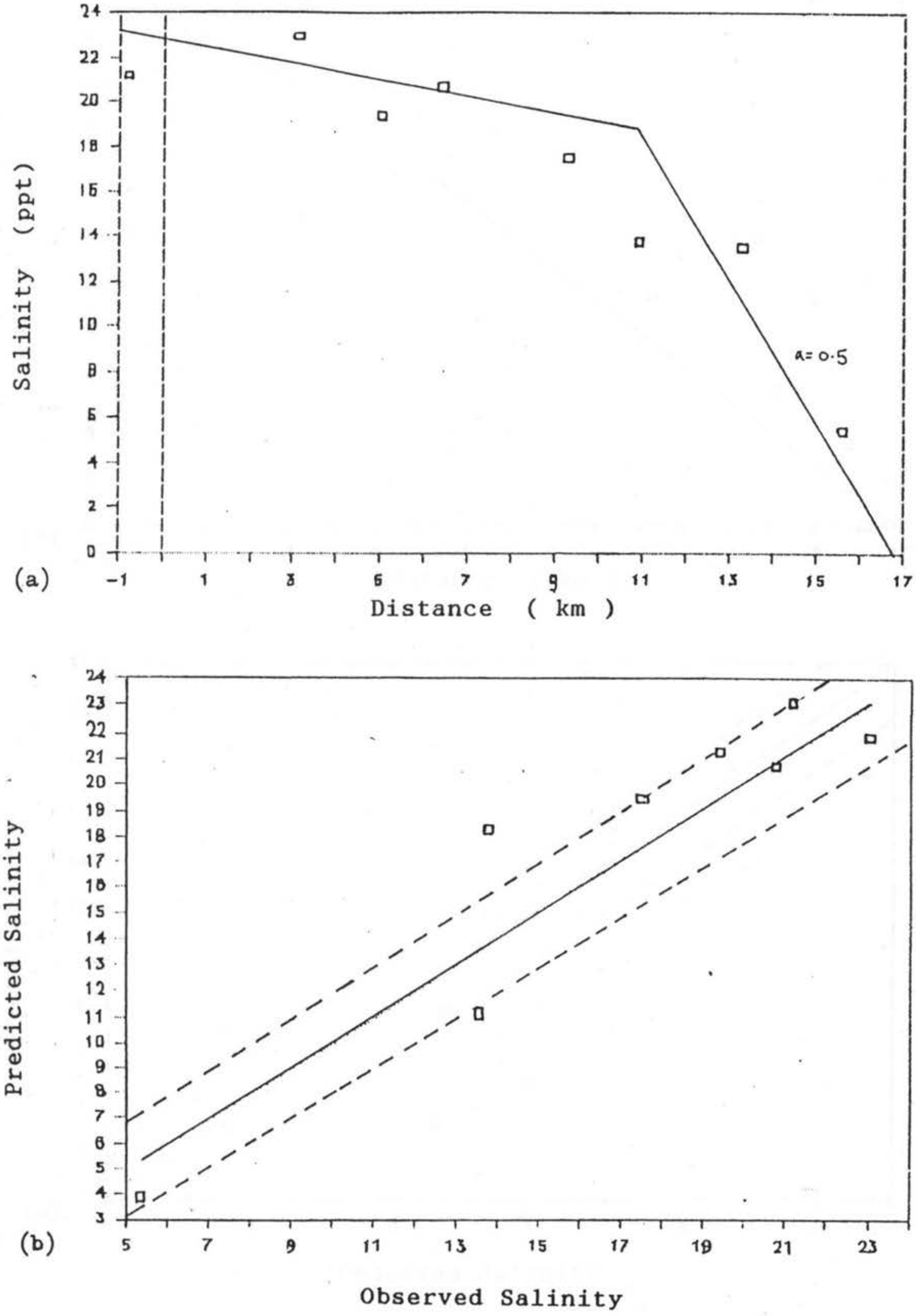


Figure 4.24a &b Comparison Between Observed Data and Predicted Data of Condition SEL-NP-LW

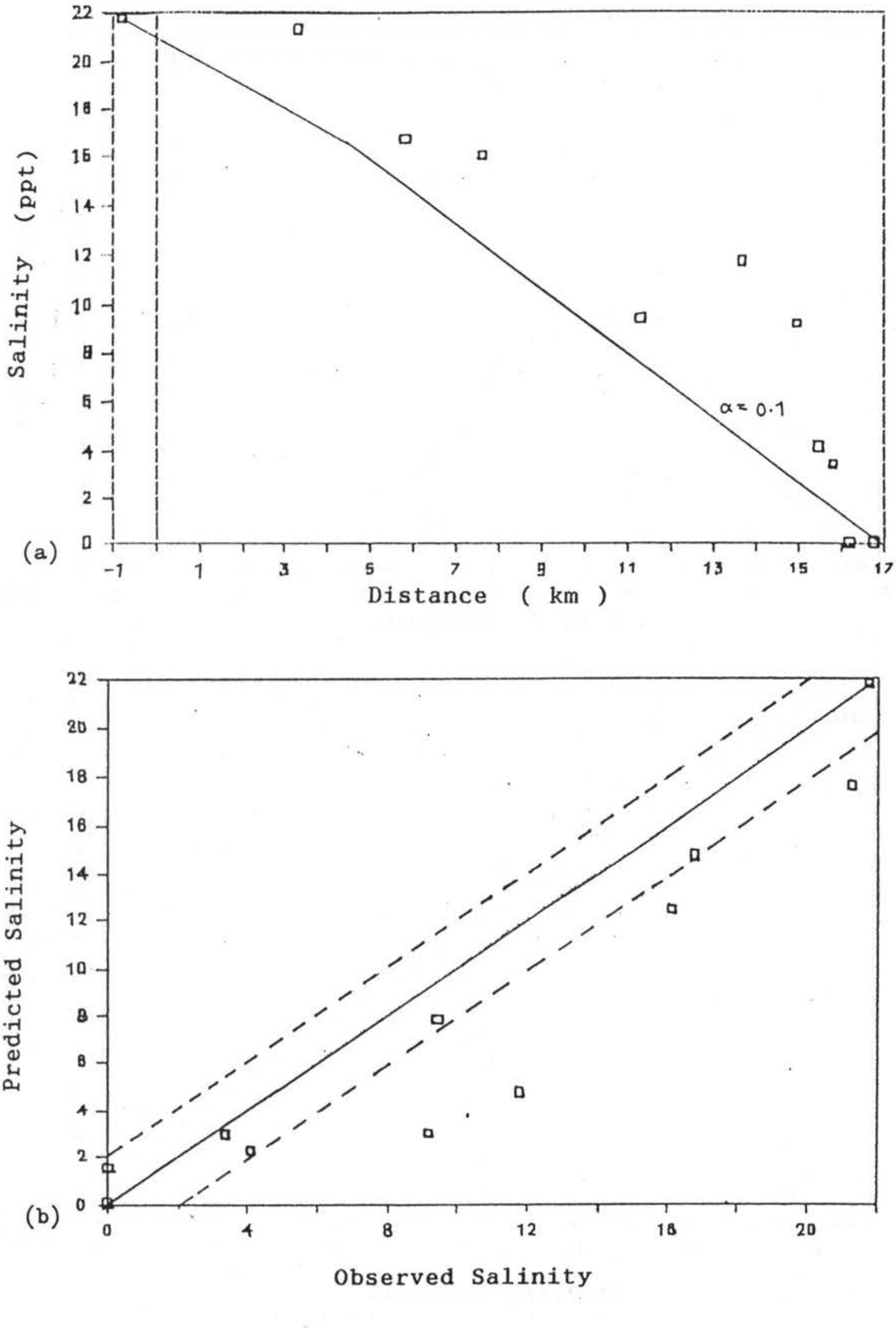
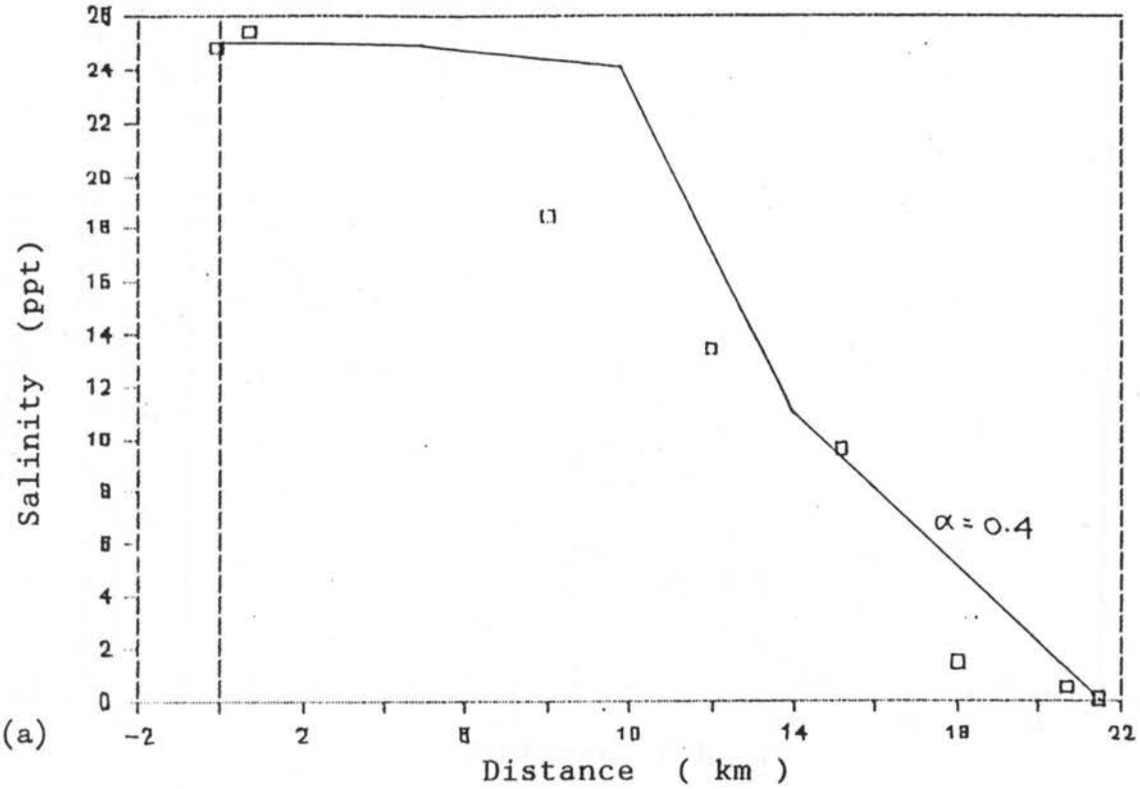


Figure 4.25a Comparison Between Observed Data and &b Predicted Data of Condition BRM-SP-HW



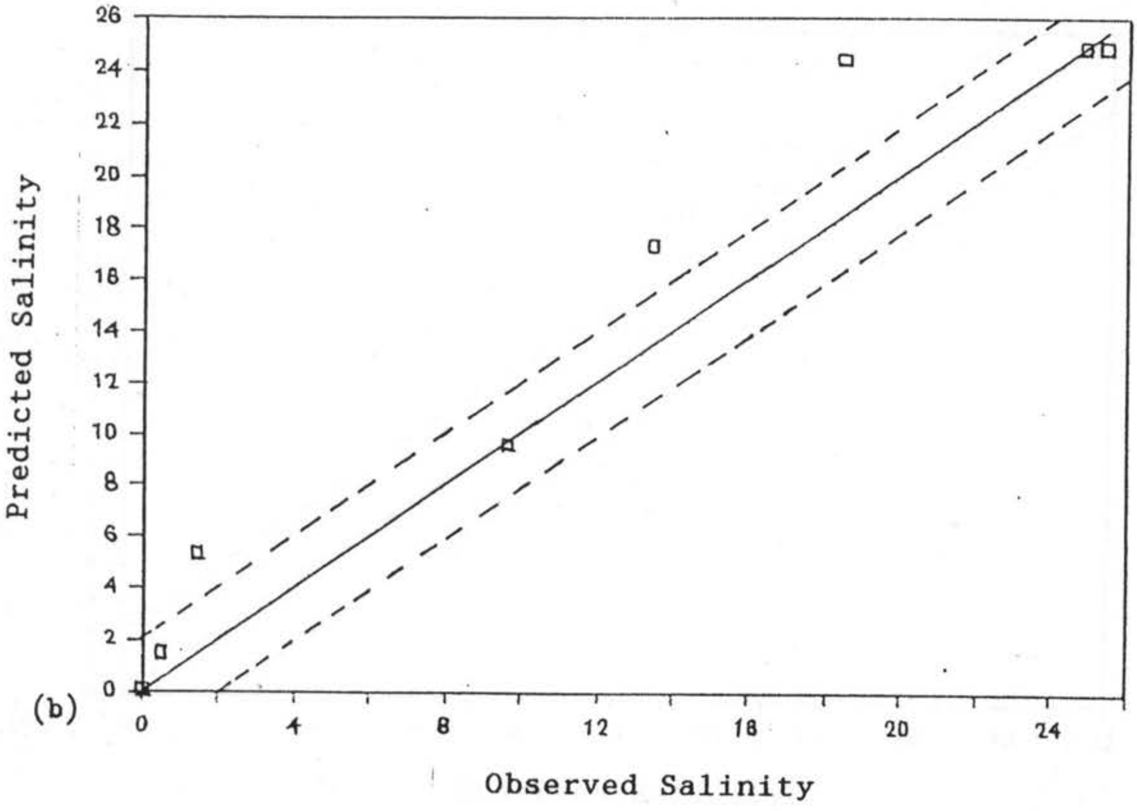
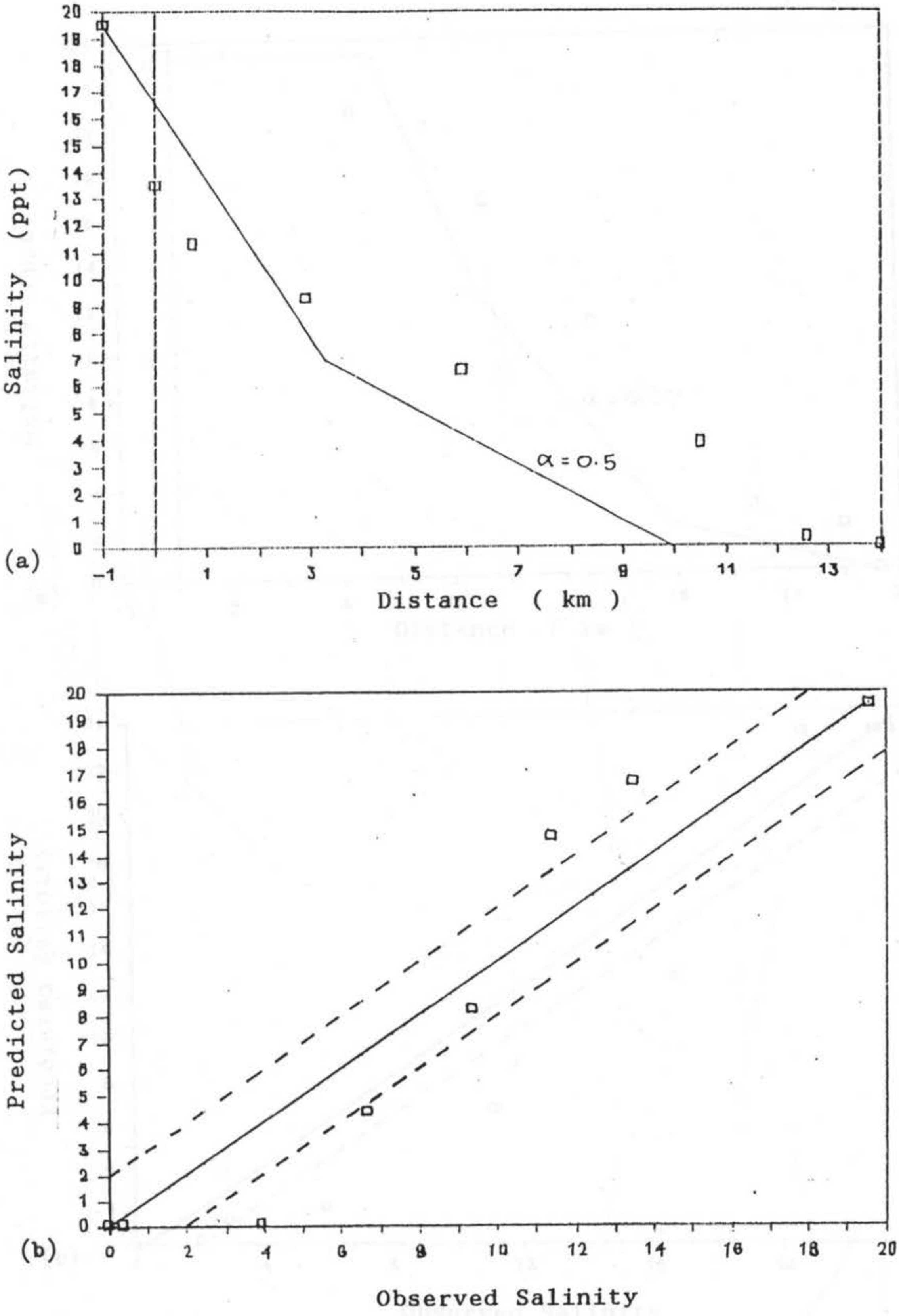


Figure 4.26a &b Comparison Between Observed Data and Predicted Data of Condition BRM-SP-LW



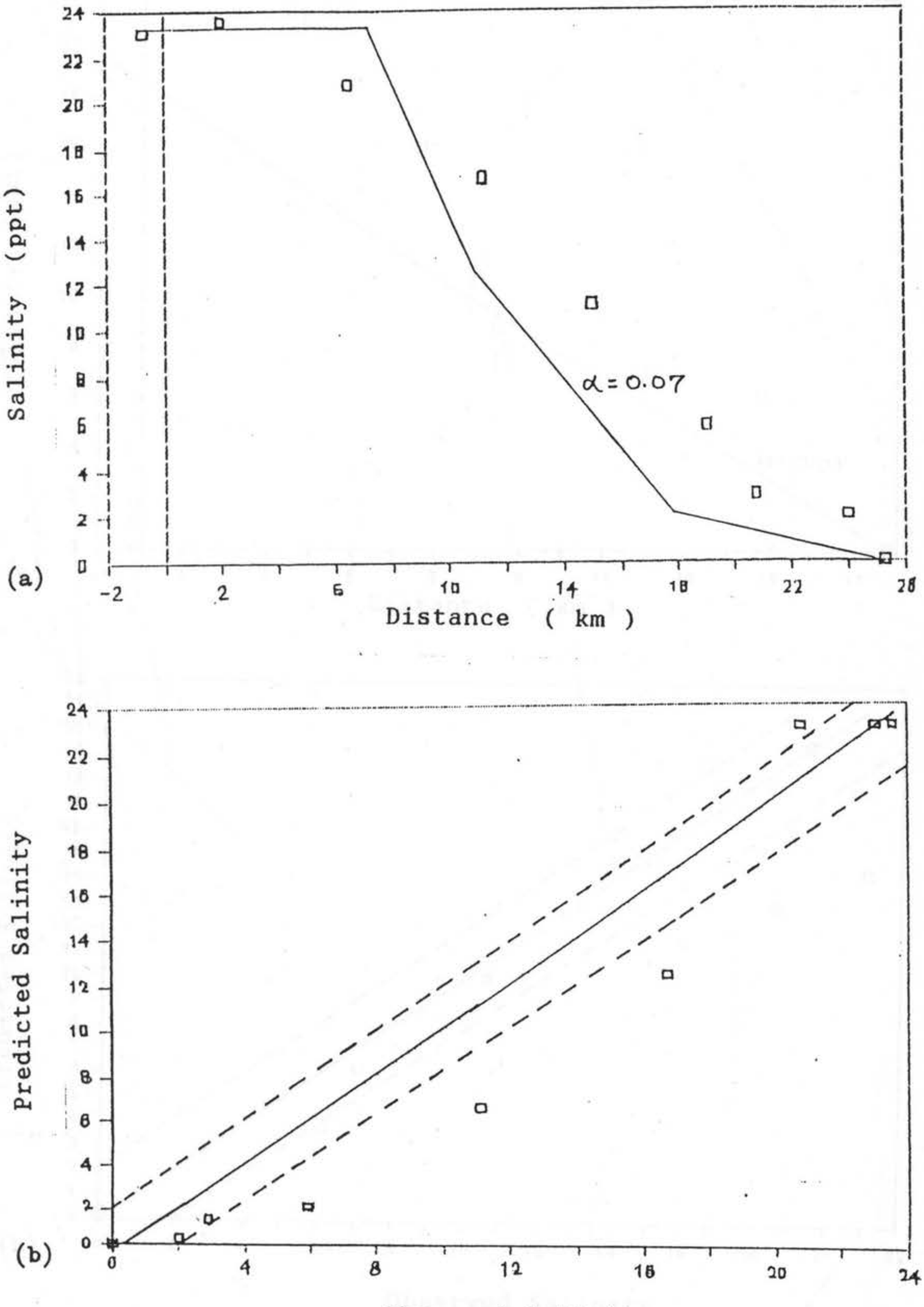


Figure 4.27a Comparison Between Observed Data and
&b Predicted Data of Condition BRM-NP-HW

Figure 4.28a &b Comparison Between Observed Data and Predicted Data of Condition BRM-NP-LW

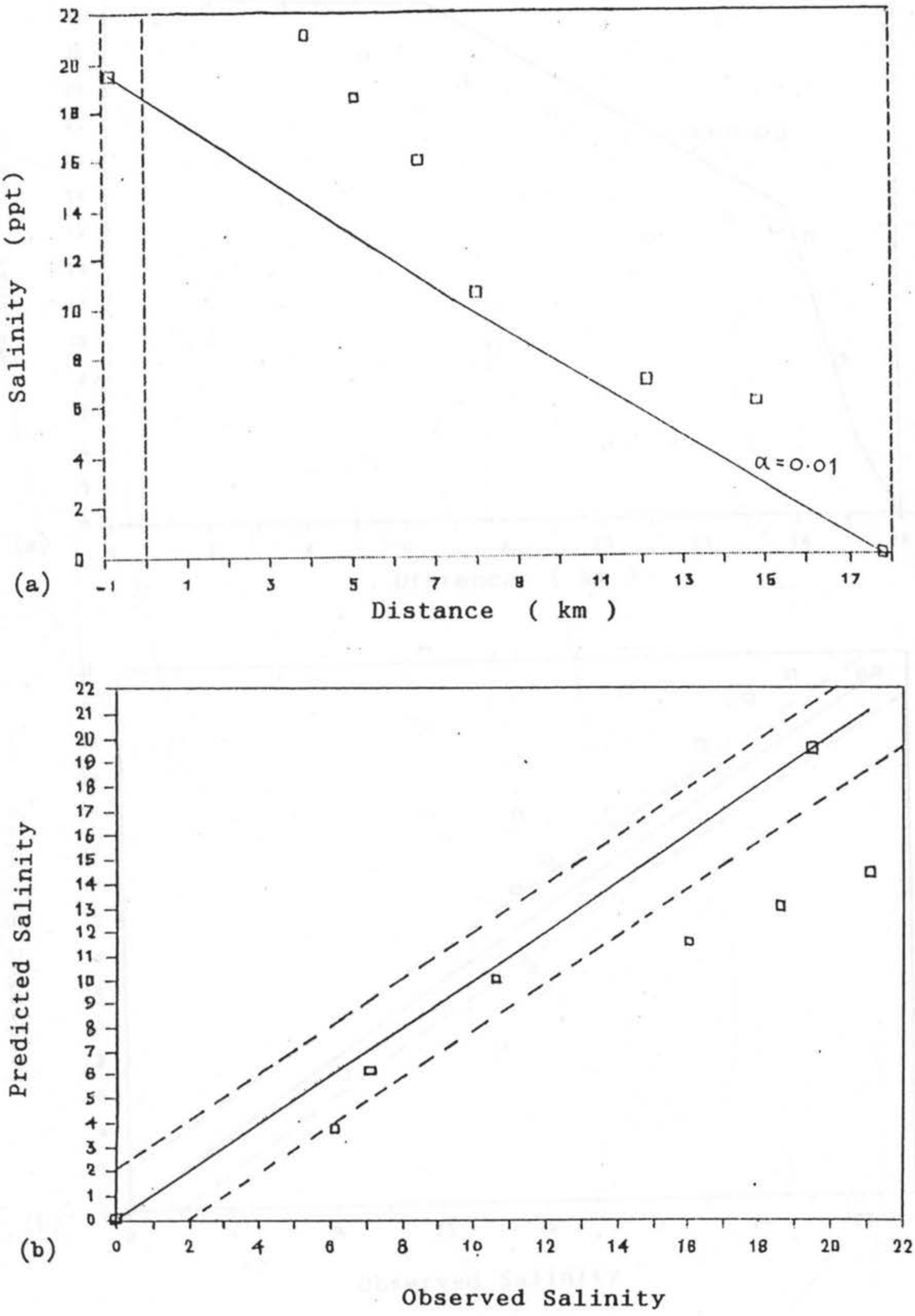
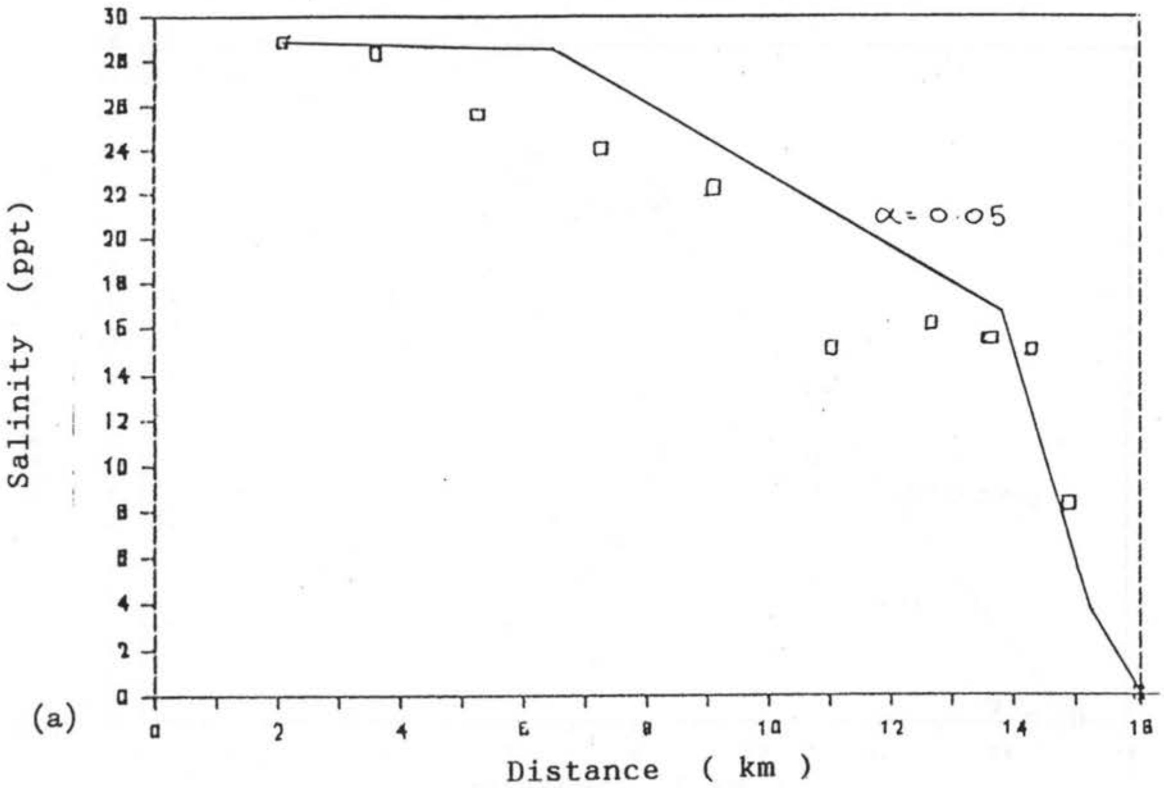


Figure 4.29a Comparison Between Observed Data and
&b Predicted Data of Condition LGT-SP-HW



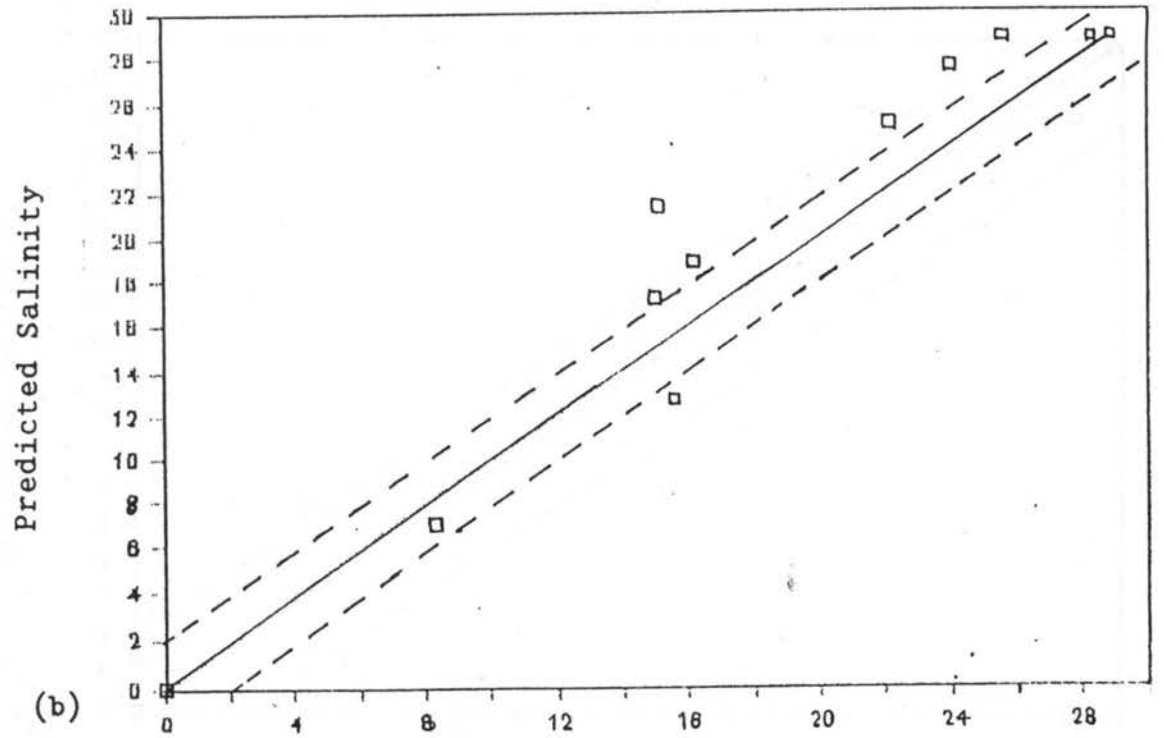


Figure 4.30a Comparison Between Observed Data and
&b Predicted Data of Condition LGT-SP-LW

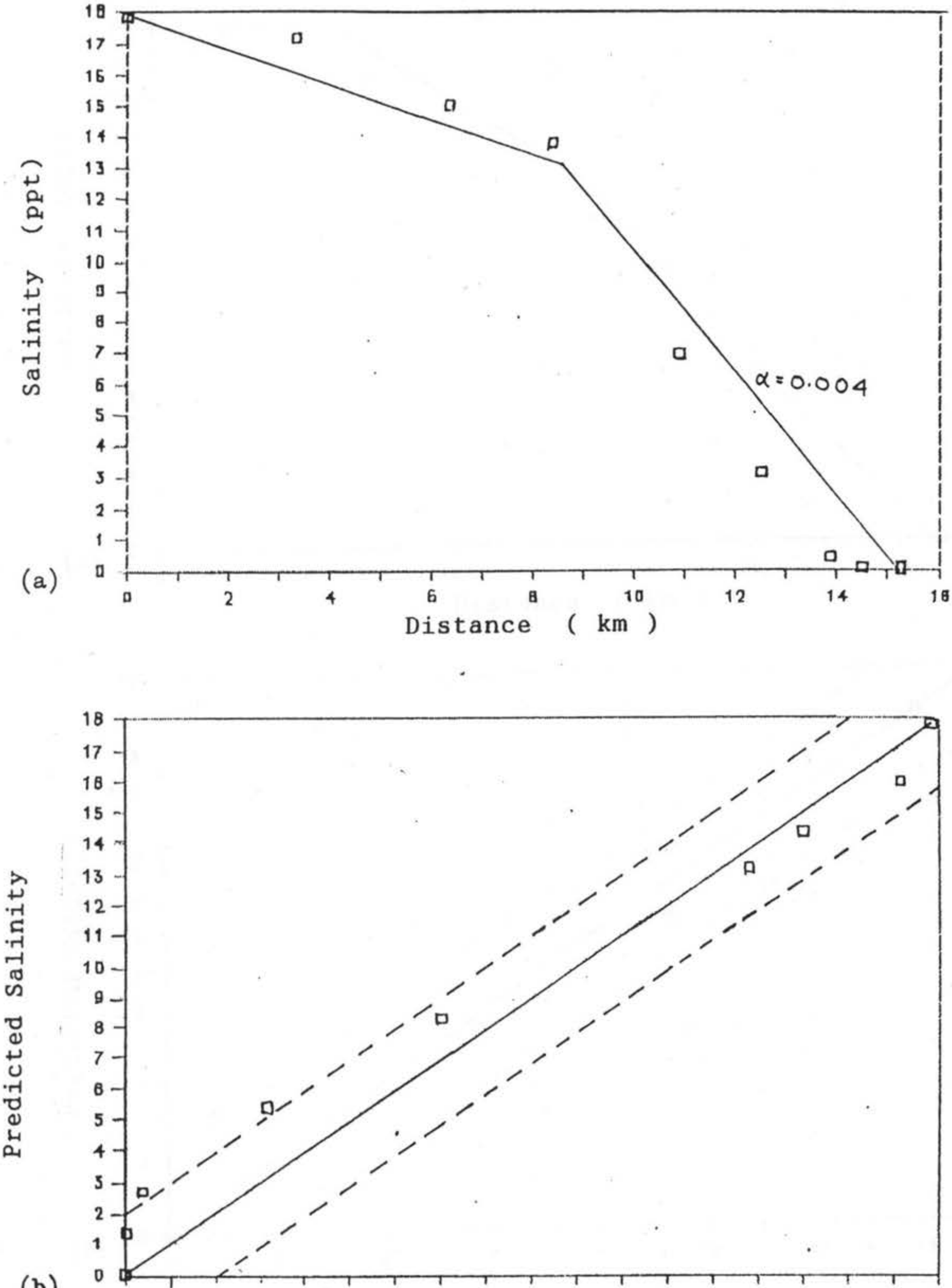
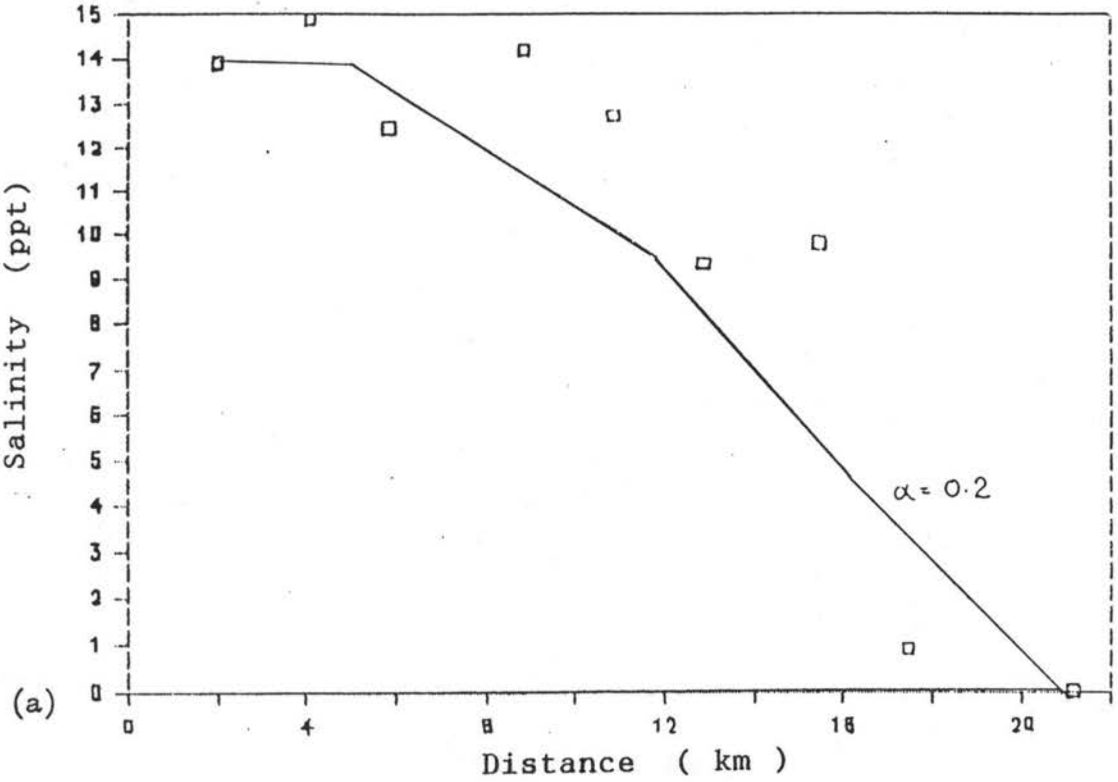


Figure 4.31a Comparison Between Observed Data and
&b Predicted Data of Condition LGT-NP-HW



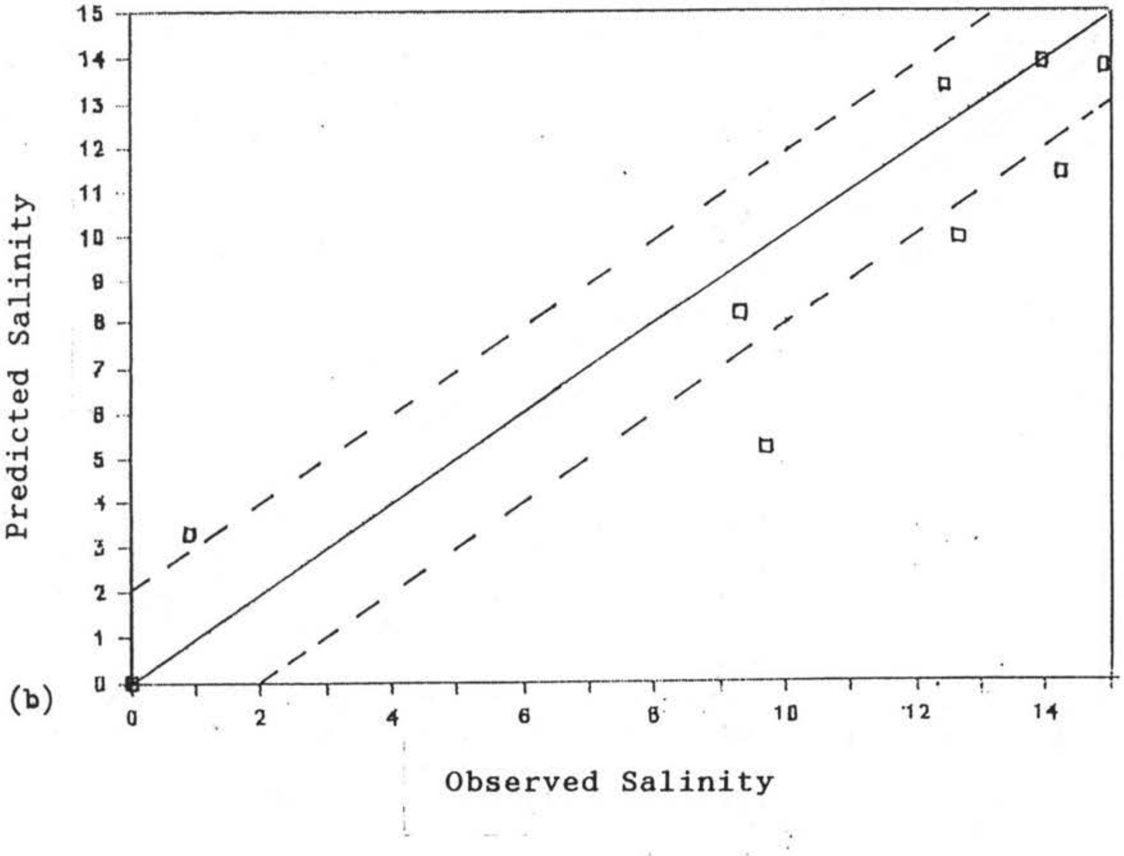


Figure 4.32a &b Comparison Between Observed Data and Predicted Data of Condition LGT-NP-LW

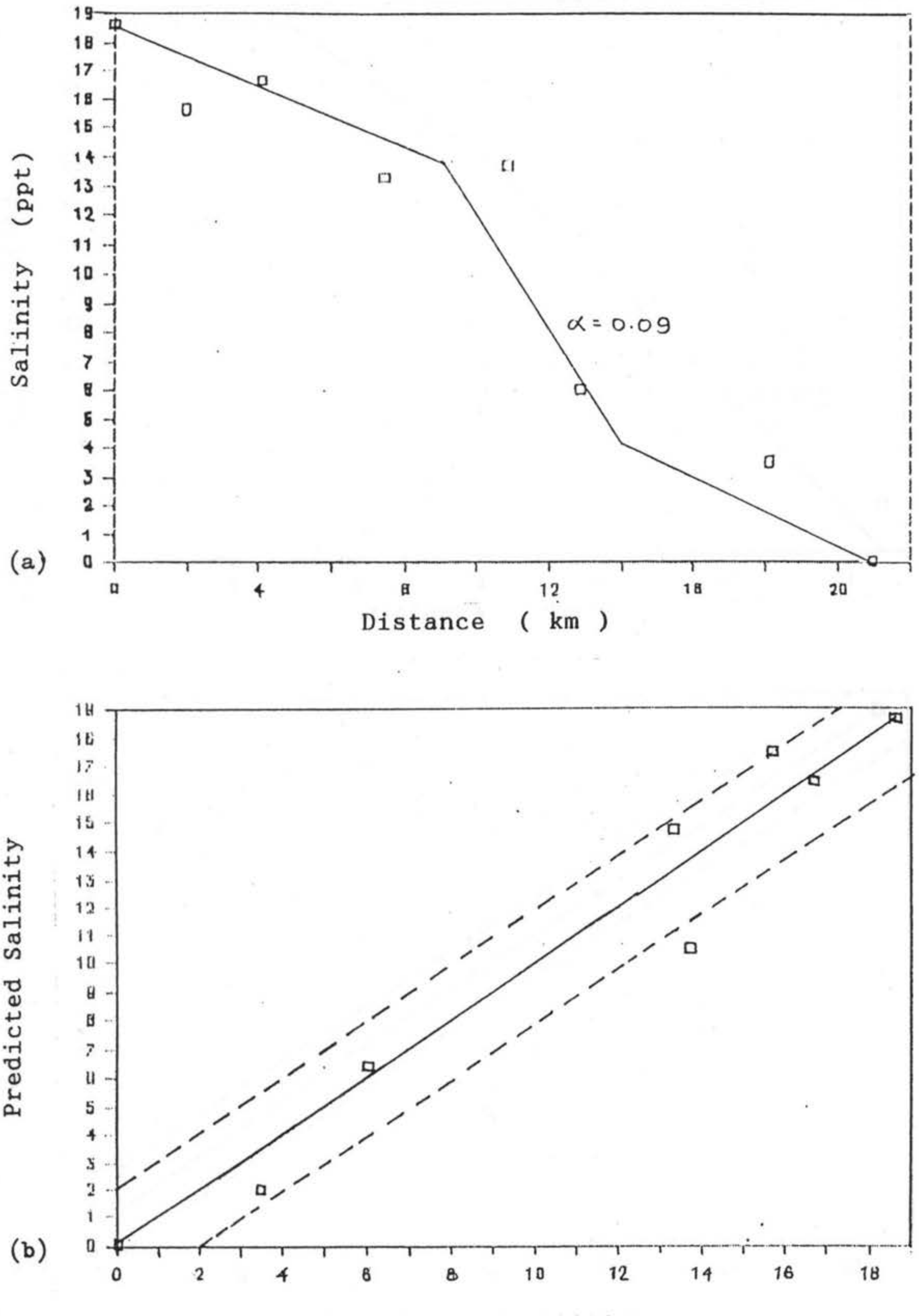


Figure 4.33a Comparison Between Observed Data and
&b Predicted Data of Condition KLG-SP-HW

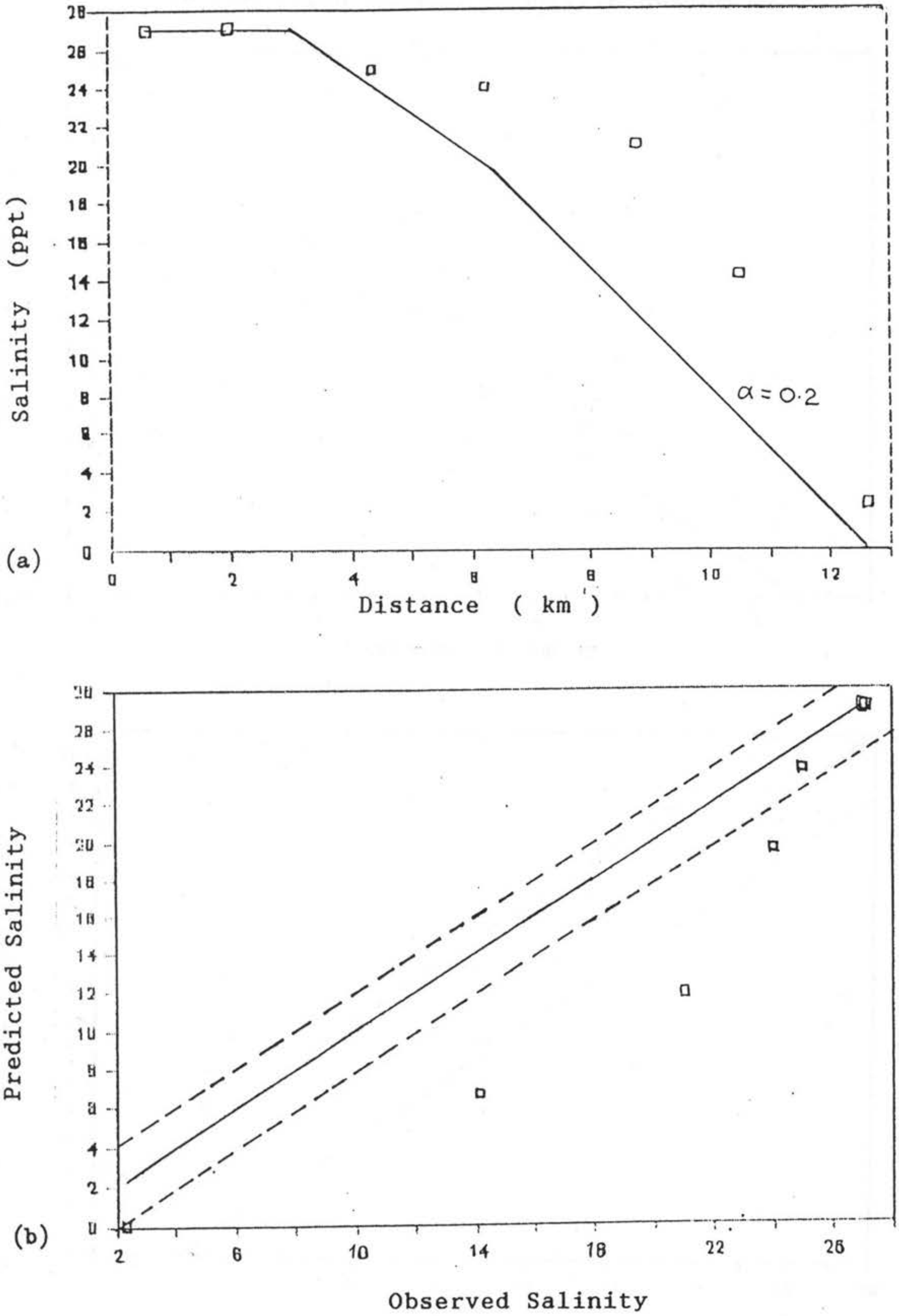


Figure 4.34a Comparison Between Observed Data and
&b Predicted Data of Condition KLG-SP-LW

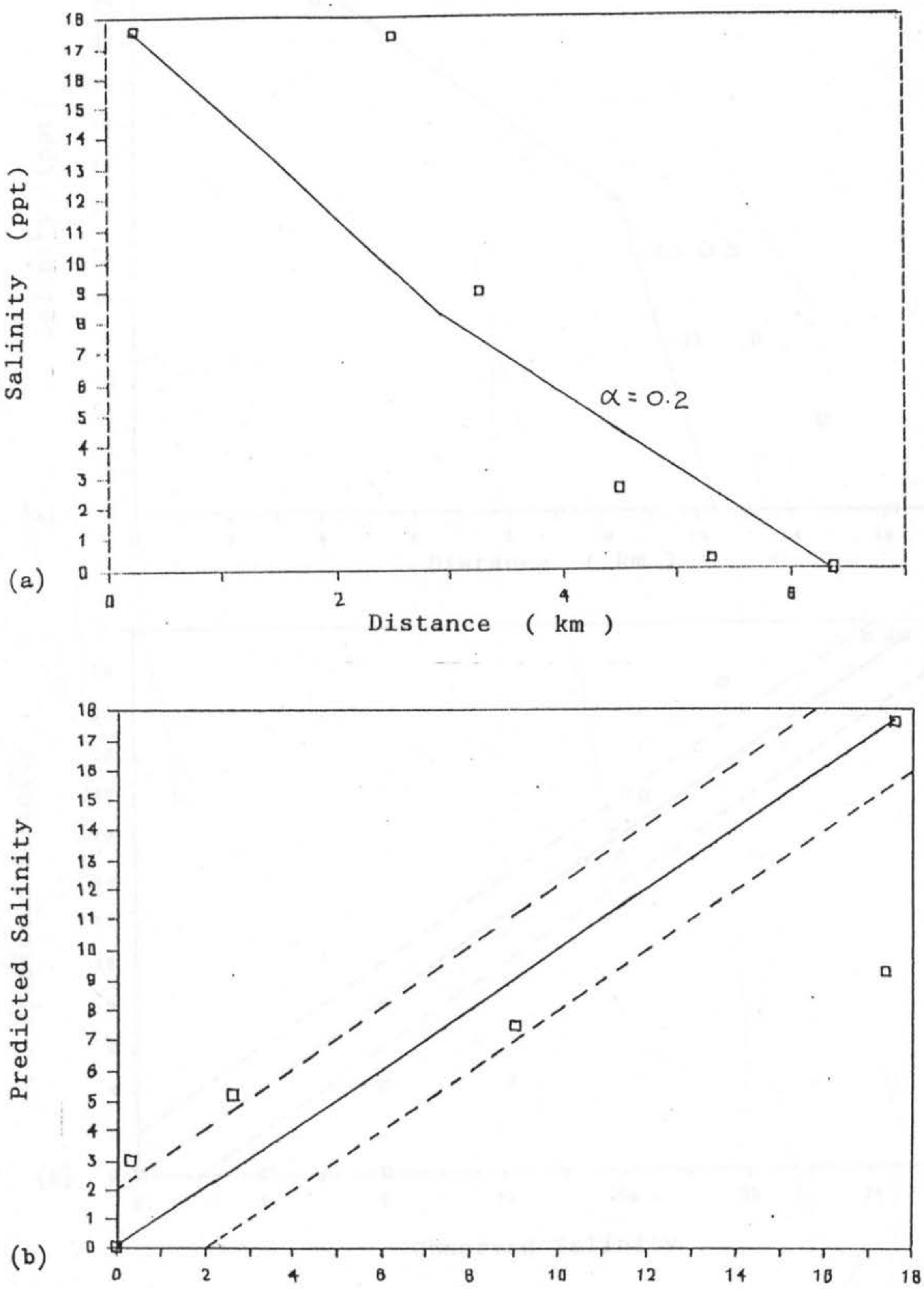


Figure 4.35a &b Comparison Between Observed Data and Predicted Data of Condition KLG-NP-HW

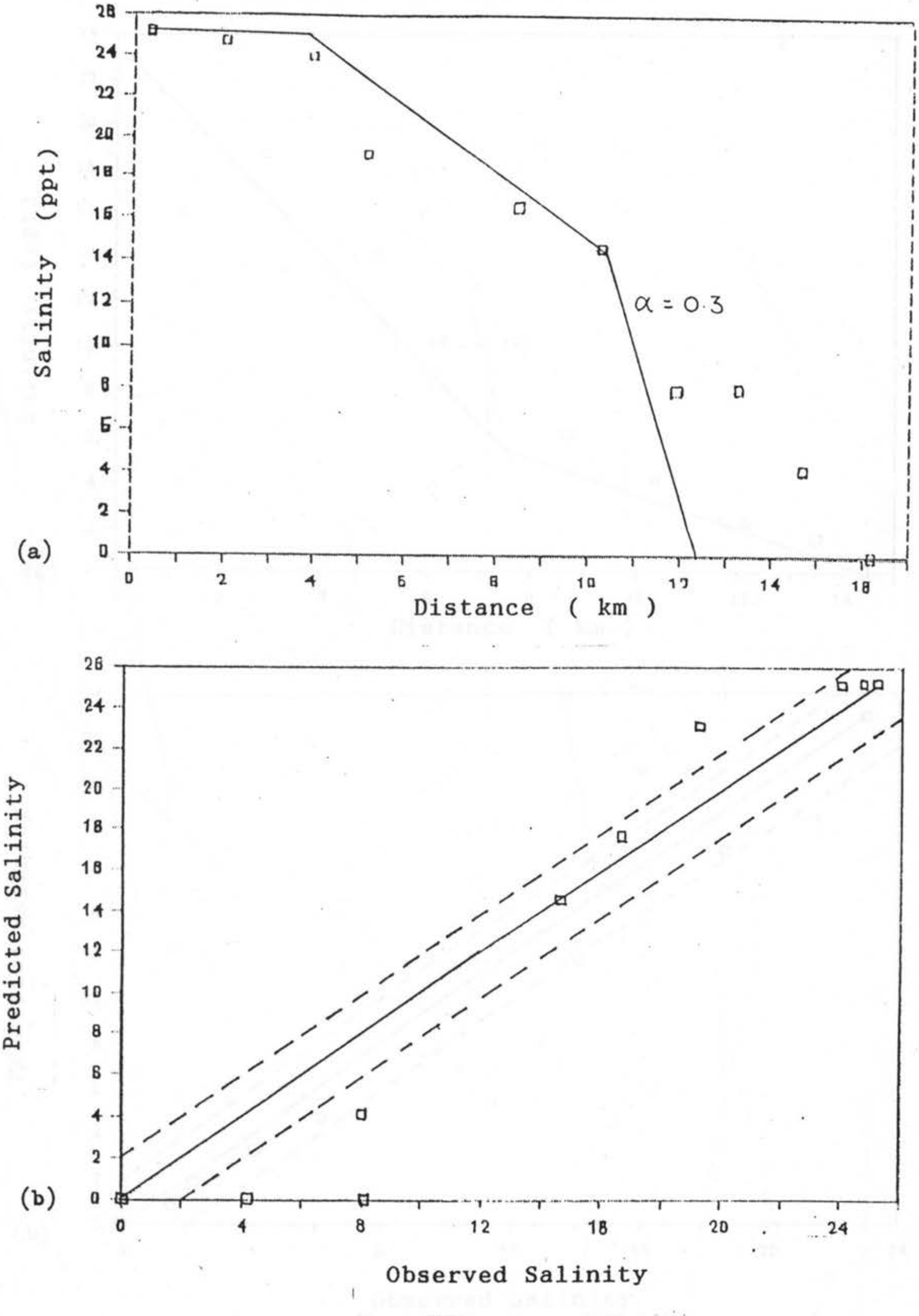
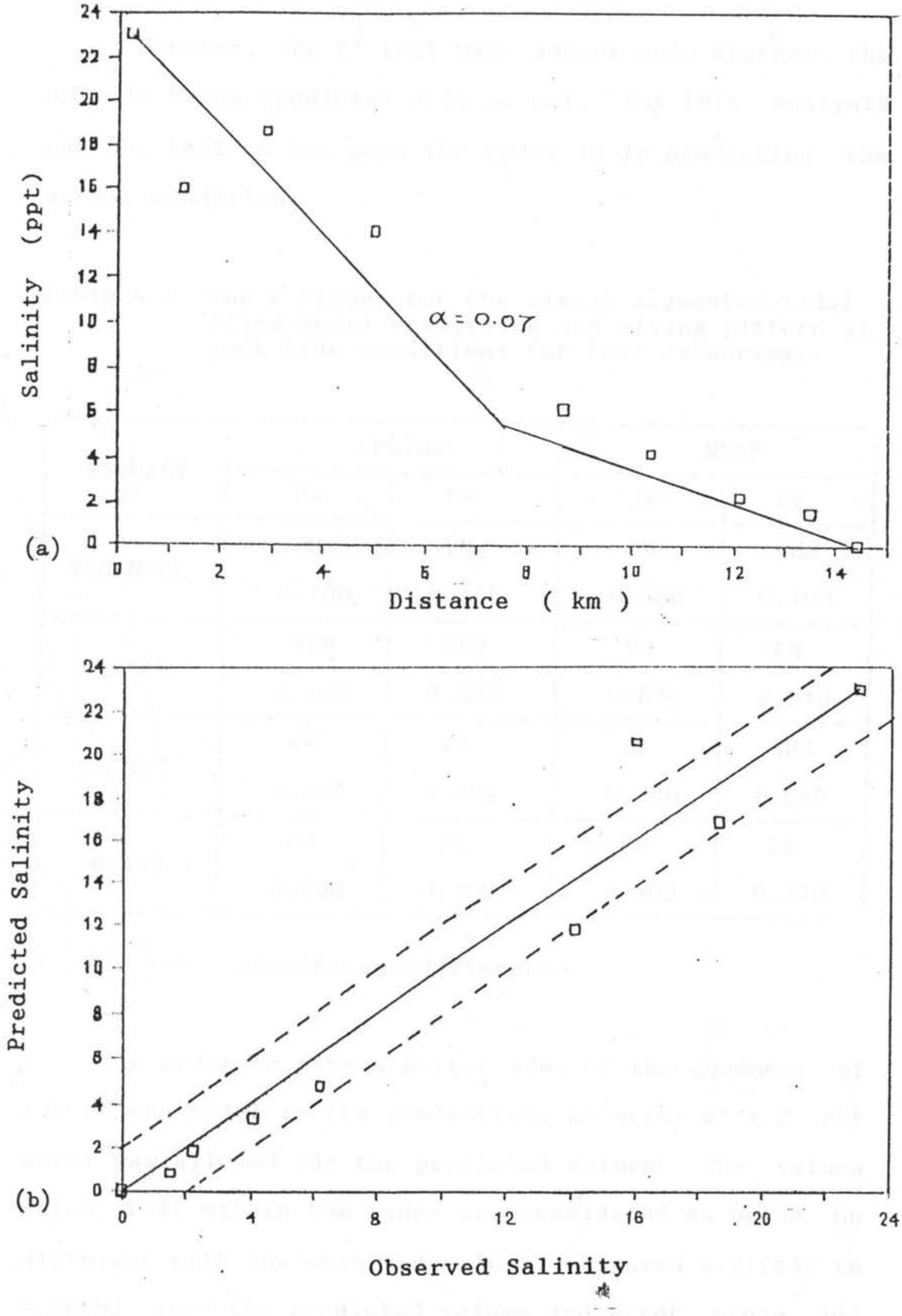


Figure 4.36a Comparison Between Observed Data and
&b Predicted Data of Condition KLG-NP-LW



predicted by the models.

However, the χ^2 test will answer only whether the data is being predicted well or not. But this analysis can not tell us how good the model is in predicting the actual condition.

Table 4.4 The a values for the simple segmented tidal prism model prediction and mixing pattern of each tide conditions for four estuaries.

ESTUARY OF	SPRING		NEAP	
	HW	LW	HW	LW
SELANGOR	PM 0.100	PM 0.100	PM 0.500	SHS 0.100 *
BERNAM	SPM 0.400	SPM 0.500	PM 0.070 *	PM 0.010
LANGAT	WM 0.050	WM 0.004	HS 0.200	SHS 0.090
KLANG	PM 0.200 *	PM 0.200	HS 0.300	HS 0.070

* --> significant difference

In order to have a better idea of the goodness of fit of the model in its prediction, an error of ± 2 ppt error was allowed for the predicted values. The values which fall within the range are considered as being no different with the observed values. Figures 4.21(b) to 4.36(b) show the predicted values and error range and the observed data. The criteria used to determine the goodness of fit of the model is the percentage of data values within the allowed error range. The limit of goodness level suggested in this paper is listed in Table 4.5.

Table 4.5 Goodness of fit level of model.

% Goodness	Class
> 75%	Good
50% - 74%	Moderate
30% - 49%	Fair
< 30%	Poor

The goodness of fit level of each model is listed in Table 4.6.

Twelve out of thirteen models which have no significant difference were above 50% of goodness of fit level. There were 4 models classify as 'Good fit ' prediction models. Eight models predict 'Moderately fit' and there is only one model predicts 'Fairly fit'. No model gave 'Poor fit' prediction model.

4.2.1 Mixing Parameter

The values of mixing parameter ranged from 0.01 to 0.5 for all the estuaries under different tide

Table 4.6 Goodness of fit level of each tide conditions models.

ESTUARY OF	SPRING		NEAP	
	HW	LW	HW	LW
SELANGOR	50.0%	50.0%	75.0%	63.6%*
BERNAM	62.5%	50.0%	55.6%*	50.0%
LANGAT	36.4%	77.8%	55.6%	87.5%
KLANG	42.9%*	50.0%	60.0%	77.8%

* --> significant difference

conditions (Table 4.4). The mixing values indicates the percentage of water movement from one segment to another. For example, for Sg. Langat with the mixing parameter of a=0.05 it indicate that only 5% of well mixed water in a segment will moves to the next adjacent segment. Therefore, if the model for tide condition has a higher mixing parameter value, a higher percentage of well mixed water will be moved.

Dyer and Taylor stated that the simple segmented tidal prism model is valid for well mixed and partially mixed estuaries. However, in this case, it seems that the model could also predict well for highly stratified estuaries. That is for Sg. Klang during neap tide at low water which was found to be highly stratified and Sg. Langat during neap tide at both high and low water which was slightly highly stratified. Also, the χ^2 test showed that they are among the tide conditions which has no difference in salinity between observed and predicted values; and thus are being well predicted by the models. However, there also cases where partially mixed estuaries are not being well predicted such as tide condition of Sg. Klang at spring tide high water (KLG-SP-HW) and Sg. Bernam neap tide high water (BRM-NP-HW).

There are three cases which has significant difference between the observed values and the predicted values. These are the tide conditions of Sg. Selangor during neap tide at low water (SEL-NP-LW), Sg. Bernam during neap tide at high water (BRM-NP-HW) and Sg. Klang during spring tide at high water (KLG-SP-HW). The behaviour of these estuaries ranged from partially mixed to highly stratified mixed.

The cause of the three significant difference cases may be due to the assumption of complete mixing is not fulfiled. The average salinity value of a particular segment volume in that estuaries did not indicate the mixing process as the complete mixing in stratified type of estuary is unlikely to occur. Thus, it consequences a significant difference between the actual average salinity value and the predicted salinity value.

Another possible reason for the occurrence of the significant difference cases is, it may be related to the definition of the first segment volume of the estuary. The inappropriate definition of the first segment volume can results an overestimation or underestimation by the model.

Principally, the concept of the tidal prism model is that an equilibrium state of estuary water is conserved where the total water enter the estuary system must equally to that moving out of the system. But in actual situation the equilibrium state is not really conserved.

Owing to these possible water loss from or enter into the estuarine water equilibrium system, we should redefine the boundary of first segment volume in the model. From equation (2.1), the first segment volume is defined as

$$V_1 = R$$

but now the definition can be changed to :

$$V_1 = R \pm W_e \qquad (4.1)$$

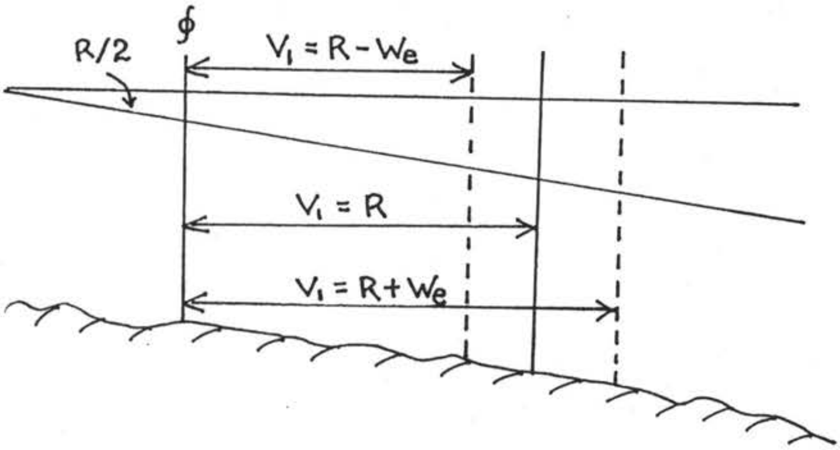
where W_e is the water loses from or enter into the estuarine water system.

For the case of decreasing in the first water volume ($-W_e$) (Figure 4.37), the estuarine water is lost through evaporation from the surface water and seepage outflow. Additional path of the water losses may through transpiration of vegetations along the estuary, especially mangrove species and increasing in the area of exposed to evaporation on the mudflats during high water. As a result, the boundary of first segment volume would be reduced and consequently the mean salinity in the particular segment is increased (Figure 4.38).

While for the case of increment in the first segment volume ($+W_e$) (Figure 4.37), the average salinity measured in the field was more diluted by the additional fresh water. This indicated that there exist other sources of fresh water input into the estuary water. The source may be due to changes in river discharge resulting form the storm effect. Although the river discharge was assumed to be constant at all time in the model but if there was storm or heavy rains occurred at up stream of the river just before the field sampling was conducted, it could cause the sudden increase in river discharge.

Another possible reason responsible for the increased segment volume is the "water storage effect".

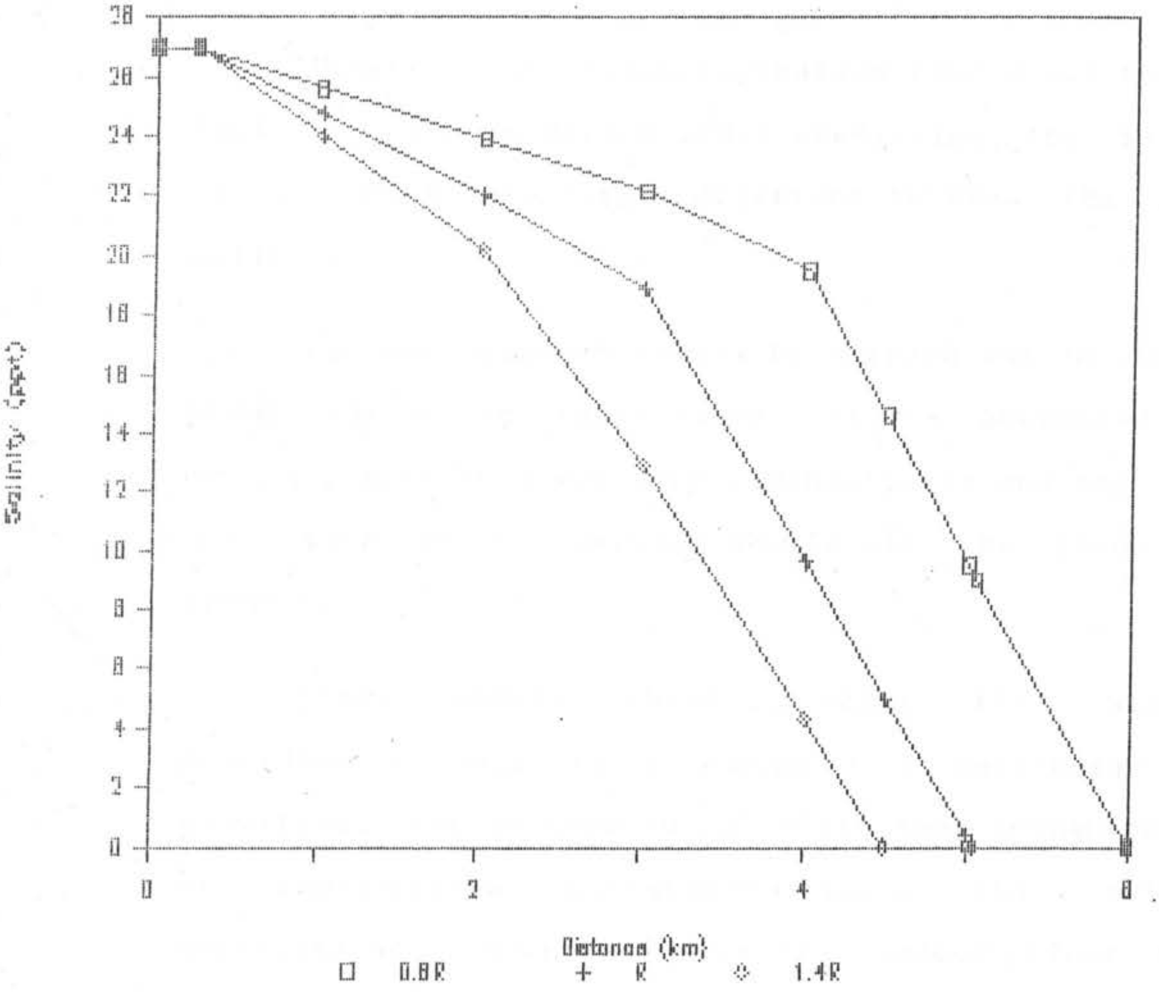
Figure 4.37 Definition of first segment volume.



Some of the estuaries, for example Sg. Selangor, the river bed is undulating where there exists "pockets" which could trapped water from moving (Figure 4.5). As low tide more fresh water tends to trapped in the "pockets"; while high water tide the incoming seawater will then be diluted by the fresher water storage. In addition, water inflow from seepage also can cause an increase in the segment volume. Consequently, it reduced the average salinity value in the increased segment volume (Figure 4.38).

However, the W_e parameter introduced above is mainly for conceptual explanation. The parameter by itself may also involved many environmental parameters which are not yet been established, and therefore need further studies and researches.

Figure 4.38 Diagram showing the changes in the predicted values curve after redefinition the first segment volume (In this case $W_e = \pm 0.4R$ was used).



4.2.2 Modification of Model

For the three cases where there was significant difference between observed and predicted salinity values, an attempt was made to parameterise the mixing parameter values as a linear equation (see section 3.3.2). Therefore, a varies and not constant mixing parameter was assumed to vary with the estuary length in the linear function.

However, the parameterisation turned out to be a failure. The modified model predicting the salinity values which gave larger different between the actual salinity.

Further research should be carried out in order to model better in these cases. It is suggested that mixing parameter might vary exponentially and the depth and width of the estuary should also be taken into account.

Those models which predict the salinity distribution well in a estuary of particular tide condition, can be used to calculate the concentrations of conservative pollutants along the estuary. Conservative concentration is the concentrations whose values do not change in the course of a particular series of events (Baker et. al., 1966). The conservative concentrations are altered locally except at the boundary, by the processes of diffusion and advection only (Hunt and Groves, 1965). However, it works only if the concentration of particular pollutant in pure seawater is known.

4.2.3 Flushing Time

The results of the computation for all four estuaries are shown in Table 4.7. The total mean volume of estuary water varied from about 3.53×10^6 m^3 to 17.52×10^6 m^3.

When each segment volume of the estuary water is divided by the river discharge per tidal cycle, which is the time required by the fresh water volume to flush out to the sea through the estuary, the summation of the flushing time for all four estuaries ranging from 1.47 tidal cycles to 8.79 tidal cycles (Table 4.7). In the high river discharge estuaries of Sg. Selangor and Sg. Bernam, the flushing time ranged from 2.19 tidal cycles to 6.17 tidal cycles (Table 4.7). In the low river discharge estuaries of Sg. Klang and Sg. Langat, the flushing time ranged from 1.47 tidal cycles to 8.79 tidal cycles (Table 4.7).

The shortest flushing time for Sg. Selangor is 2.19 tidal cycles during neap tide at high water, for Sg. Bernam and Sg. Langat it is 3.08 tidal cycles and 2.47 tidal cycles respectively at spring tide high

Table 4.7 Water volume and flushing time for different tide conditions of all estuaries.

Category	Estuary of	Tide Cond.		Water Volume ($x10^6m^3$)	Flushing Time (tc)*
High River Discharge	SEL	SP	HW	8.72	3.62
			LW	7.32	3.04
		NP	HW	5.26	2.19
			LW	6.75	2.81
	BRM	SP	HW	7.42	3.08
			LW	13.20	4.65
		NP	HW	9.23	3.84
			LW	17.52	6.17
Low River Discharge	LGT	SP	HW	5.95	2.47
			LW	12.30	8.79
		NP	HW	6.27	2.61
			LW	8.72	6.24
	KLG	SP	HW	3.53	1.47
			LW	3.70	2.94
		NP	HW	3.89	1.62
			LW	4.18	3.32

* tc ==> tidal cycle

water. For Sg. Klang it is 1.47 tidal cycles, also during spring tide at high water (Table 4.7).

All of the shorter flushing times occur at high water during spring and neap tide for the four estuaries.

The best tide period for any waste disposal should introduced to the estuary is during the shortest flushing time. Some estuaries may have about the same flushing time at all conditions. For instance Sg. Klang the waste disposal activities can proceed at any time. Whereas for the estuaries such as Sg. Bernam and Sg. Langat, the flushing time varies at different tide periods. Therefore the waste disposal activities are restricted only at particular times.

On the other hand, if the highly stratified estuary and well mixed estuary have similar flushing rate and amount of pollutants, the highly stratified estuary will flushed out more pollutants in a particular segment volume as the pollutants were more concentrated at the fresher layer. The Sg. Klang and Sg. Langat during neap tide are likely to perform the similar condition to that highly stratified estuary.

In the well mixed estuary, less pollutants will be flushed out compared to highly stratified estuary. This is because in the same segment volume the concentration or amount of pollutants are diluted compared to the highly stratified estuary. In other words, these pollutants are tend to be retained longer in a well mixed estuary. It is likely that Sg. Langat during spring tide and those partially mixed estuaries such as Sg. Bernam, have this condition.

4.2.4 Can This Model Be Widely Used ?

The simple segmented tidal prism is a gross simplification of the hydrodynamics effects that occurs in the estuary. This model can only be used to indicate the average condition of salinity and any conservative constituents associated with the mixing pattern in the estuary. It does not indicate the mixing processes such as convection mixing, advection mixing and diffusion which occurs inside the estuary.

The model can be applied to actual conditions only in a well mixed to partially mixed estuary as the assumption of complete mixing is likely to occur in these type of estuaries. The reliability of the model in predicting salinity in a highly stratified estuary is most likely unacceptable.

In addition, the simple segmented tidal prism is a static model. The model can only predict the average salinity and the conservative constituent concentrations associated with the water mixing in a "box volume" at high water and low water. In other words, the salinity and concentrations values within the period of the flood and ebb are unable to be predicted by the model.

The model attempts to serve as a management tool in estuarine pollution control and abatement. In a baseline study, the model is able to give a satisfactory prediction of the average condition of the salinity and conservative constituent concentrations in the estuary. However, the model can not identify the sources of such a particular constituent contributed into the estuarine system. Thus, if the "pollution control at source approach" is given priority in the pollution abatement programmes, this model is not appropriate in this context.

CHAPTER 5

SUMMARY

5.1 Summary

Four major estuaries of Selangor Darul Ehsan were selected for the study. These are the estuaries of Sg. Bernam, Sg. Selangor, Sg. Klang and Sg. Langat (Figure 1.1). The field sampling was conducted between September 1991 to January 1992. The field sampling was carried out during spring and neap tide for all four estuaries (Table 3.1). Two *in situ* measurements i.e salinity and temperature were taken during each sampling field trip.

The project was successfully completed for the first comparative study on classifying the individual estuaries of Sg. Bernam, Sg. Selangor, Sg. Klang and Sg. Langat on the salinity structure. The behaviour of the salinity structure in the estuaries during neap and spring tides at both high water and low water was also observed.

A mixing salinity ratio diagram modified from the Stratification Number classification (Ippen and Harleman, 1961) was used in determining the behaviour of the estuaries. Overall, Sg. Bernam is a Partially Mixed estuary, Sg. Selangor is a Partially Mixed estuary except during neap tide at low water where it behaves as a Slightly Highly Stratified estuary. Sg. Klang is a Partially Mixed estuary during spring tide but is Highly Stratified during neap tide, and Sg. Langat is a Well Mixed estuary during spring tide but a Slightly Highly Stratified estuary during neap tide.

Box modelling of the estuaries was also carried out by using Dyer and Taylor's (1973) simple, segmented tidal prism model. This model could be applied to satisfactorily predict the models of 13 out of 16 tide conditions for all four estuaries (Table 4.3). Among the 13 reliable models, 4 models can predict Good fit (> 75% of the observed data), 8 models predict Moderate fit (50% - 74% of observed data) and only one model predicts Fair fit (30% - 49% of observed data). No model predicted Poor fit.

The model may predicts the other conservative constituents concentration including the pollutants at high water and low water with the condition that the constituents have the similar mixing behaviour to that of salinity.

The concentration of any associated conservative pollutant introduced to the estuary can be directly derived from the model by substituting the parameter C^H and C^L with the pollutant's concentration instead of salinity.

The flushing time for all four estuaries at different tide conditions were calculated (Table 4.7). The knowledge of flushing time of each estuary during different tide periods will enable us to choose the appropriate tide condition for waste disposal. The shortest flushing time is most preferable. The shorter the flushing time required to flush from the upper-end of the estuary to the sea, the lesser the damage caused by the pollutant's effects upon living aquatic organisms. This step will ensure that the pollution to the estuarine environment will be minimal.

Understanding the behaviour of a estuary will allow us to select the most favorable tide period for the dispersal of associated pollutants with the estuarine water. However, each mixing pattern will resulted in different implications on the surrounding environments.

The results obtained from this project study can be used as one of the management tools for estuarine pollution control. It permits a preliminary baseline assessment of the variation in an observed quantity which may be associated with other constituents in estuaries. It also increases and improves the knowledge regarding the salinity mixing and distribution in the estuaries.

As for the box modelling sections, it attempts to model and predict the behaviour and movement of conservative water quality parameters within the estuarine system. The generated models may be useful for coastal management decisions with regard to pollution abatement.

In conclusion, the pollution which is caused by the introduction of a diverse range of materials, human activities, navigation etc., in such quantities that the estuarine environment is made less suitable for existing life forms, it is hoped that the efforts put into this study can contribute to the management and control of the pollution. As a result of the study that contributing to estuarine pollution control, we may conserving a harmonic atmosphere between living life forms and the estuarine environment.

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APPENDIX A.1

NOTATION

a => mixing parameter

area => cross section area

cum_seg_x => cumulative distance of estuary begin from the upper-end estuary

cum_vol => cumulative segment volumes

cum_V => cumulative volumes computed from the physical dimensions inputs

init => initial mixing parameter value

kec => gradient of cumulative segment volume curves

kec_a => gradient of mixing parameter as a function of estuary distance

L => the location/ distance from river mouth of particular segment volume

P => tidal prism

Rs => river discharge

seg_x => the length of estuary where segment volume designated by the model

V => volume computed from the physical dimensions inputs

vol => segment volume designated by the model

W => width of estuary

X => distance/length of estuary

Z => depth of estuary at high water

APPENDIX A.2

```
Program Tidal_Prism ;

{ This program is written based on the simple, segmented
tidal  prism model proposed by Dyer and  Taylor  (1973).
The program will produce an output on the segment volume
and segment distance from river mouth for high water and
low  water  with inputs of (i) physical  dimensions  i.e
depth, width and length, (ii) constant river  discharge,
and (iii) constant mixing parameter. }


Uses Crt ;

Const
     m = 2 ;
     k = 250 ;
     b = 250 ;

Var

   area, kec, w, z : array [1..m, 1..k] of real ;
   x, V, vol, cum_vol : array [1..m, 0..k] of real ;
   cum_seg_x, a, cum_V, seg_x, L, P : array [0..b] of
                                           real ;
   select, g, h, n, r, i, j : integer ;
   input : char ;
   max, Rs : real ;
   condition : boolean ;


Procedure zero_value ;
begin
     For i := 1 to m do
     begin
          x[i,0] := x[i,1]+x[i,1]-x[i,2] ;
          V[i,0] := 0 ;
          vol[i,0] := 0 ;
          cum_vol[i,0] := 0 ;
        end;
     seg_x[0] := 0 ;
     cum_V[0] := 0 ;
  end;


Procedure input_vol_dim (i : integer);
begin
   j := 0;
   repeat
      j := j + 1 ;
      write ('Input DISTANCE #',j,' from river mouth (m)
               = ');
      readln (x[i,j]);
      write  ('Input DEPTH (m) at  ',x[i,j]:2:0,'m  from
```

```
                  river mouth = ');
      readln (z[i,j]);
      write  ('Input WIDTH (m) at  ',x[i,j]:2:0,'m  from
                  river mouth = ');
      readln (w[i,j]);
      writeln; writeln;
      write ('Any more data ? Press (Y) or (N).....');
      readln (input); writeln;
   until (input = 'n') or (input = 'N');
end;


Procedure vary_mix_para ;
var
   flag : boolean ;
   input1 : char ;

begin
    h := 0 ;
    flag := false ;
    While flag <> true do
    begin
        h := h + 1 ;
        write ('Input mixing parameter, a',h,' = ');
        readln (a[h]) ;
        writeln;
        write  ('Any more mixing parameter  variation  ?
                   (Y/N)..');
        readln (input1);
        writeln; writeln;
        IF (input1 = 'N') or (input1 = 'n') Then
           flag := true ;
      end;
end;


Procedure vol_calc ;
var
   i, k : integer ;

begin
      CASE select OF

     1 : begin  {Trapizium }
         For k := 1 to j do
         begin
            w[1,k] := (w[2,k]/2)*(1 + (z[1,k]/z[2,k])) ;
            area[1,k] := (z[1,k] * w[2,k]/2)*((z[1,k] /
                             z[2,k]/2)+1) ;
            area[2,k] := 3/4*w[2,k]*z[2,k];
          end;
         For i := 1 to m do
         begin
```

```
                For n := 1 to j-1 do
                begin
                  vol[i,n] := (x[i,n]-x[i,n+1])*(area[i,n]
                               + area[i,n+1])/2 ;
                  cum_vol[i,n] := cum_vol[i,n-1]+vol[i,n]
                 end;
               end;
            end;

        2 : begin  {Rectangle}
              For i := 1 to m do
              begin
                  For n := 1 to j-1 do
                  begin
                     vol[i,n] := (x[i,n]-x[i,n+1])*((z[i,n]
                                 * w[i,n]) + (z[i,n+1] *
                                 w[i,n+1]))/2 ;
                    cum_vol[i,n] := cum_vol[i,n-1]+vol[i,n];
                   end;
                 end;
               end;
        end;
   end;


   Procedure vol_output;
   begin
        writeln ('x(m)':12,'w(m)':12,'z(m)':12,'vol(m3)'
                   :12,'cum_vol (m3)':15);
        For i := 1 to m do
        begin
             For n := 1 to j do
             begin
                  writeln (x[i,n]:12:0,w[i,n]:12:0,z[i,n]
                             :12:1,vol[i,n-1]:12:1,cum_vol
                             [i,n-1]:15:1);
               end;
             writeln; writeln;
             readln ;
           end;
   end;


   Procedure gradient_calc ;
   begin
       For i := 1 to j-1 do
       begin
          kec[1,i] := (cum_vol[1,i]-cum_vol[1,i-1])/(x[1,i]
                       - x[1,i-1]) ;
          kec[2,i] := (cum_vol[2,i]-cum_vol[2,i-1])/(x[2,i]
                       - x[2,i-1]) ;
        end;
     end;
```

```
Procedure seg_vol_calc (i : integer) ;
var
   j, n : integer ;
   flag1, flag : boolean ;

begin
     n := -1 ;
     flag := false ;
     While flag <> true do
     begin
          n := n + 1 ;
          IF (V[1,i] > cum_vol[1,n]) AND
               (V[1,i] < cum_vol[1,n+1]) Then
          begin
               seg_x[i] := V[1,i]/kec[1,n+1] ;
               V[2,i] := kec[2,n+1]*seg_x[i] ;
               P[i] := V[2,i] - V[1,i];
               j := -1 ;
               flag1 := false ;
               While flag1 <> true do
               begin
                 j := j + 1 ;
                 IF (cum_V[i] > cum_vol[1,j]) AND
                      (cum_V[i]< cum_vol[1,j+1]) Then
                 begin
                    cum_seg_x[i] := cum_V[i]/kec[1,n+1];
                    flag1 := true ;
                   end;
                end;
               IF i=1 Then
                  L[i] := x[1,1]
              else
                  L[i] := x[1,1] + cum_seg_x[i] ;
              flag := true ;
           end;
      end;
end;


Procedure seg_vol_output ;
var
   t : integer ;

begin
   writeln ('sg#':3,'V (m3)':12,'LW_csv':12,'HW_csv':12,
              'P (m3)':12,'X (m)':12,'L (m)':12);
   For t := 1 to r do
   begin
       writeln (t:3,' ':2,V[1,t]:10,' ':2,cum_V[t]:10,'
                 ':2,V[2,t]:10,' ':2,P[t]:10,' ':2,
                 cum_seg_x[t]:10,' ':2,L[t]:10);
```

```
       IF (t=22)or(t=46)or(t=70)or(t=94)or(t=118) Then
       begin
          readln ;
          ClrScr;
         end;
     end;
end;


BEGIN { main frame of progam }
    ClrScr ;
    writeln  ('Enter Dimension Along Estuary During  LOW
                WATER');
    writeln ;
    input_vol_dim (1);
    writeln ;
    ClrScr ;
    writeln ('Enter Dimension Along Estuary During  HIGH
               WATER ...');
    writeln ;
    input_vol_dim (2);
    writeln ;
    ClrScr ;
    Gotoxy(1,5);
    write ('Input River Discharge per Tidal Cycle, Rs =
             ');
    readln (Rs) ;
    writeln; writeln;
    writeln ('Select Shape of Estuaty Cross Section Area
               : ');
    writeln ;
    write ('      (1)-Trapizium       (2)-Rectangle
            ? .....  ');
    readln (select) ;
    writeln;writeln;
    vary_mix_para ;
    ClrScr ;
    zero_value ;
    vol_calc ;
    vol_output ;
    gradient_calc ;
    max := cum_vol[1,j-1] ;
    For g := 1 to h do
    begin
         r := 1 ;
         V[1,r] := Rs ;
         cum_V[r] := V[1,r] ;
         seg_vol_calc (r) ;
         V[1,r+1] := P[r] / a[g] ;
         cum_V[r+1] := cum_V[r] + V[1,r+1] ;
         condition := false ;
         While condition <> true do
         begin
```

```
            r := r + 1 ;
            seg_vol_calc (r);
            V[1,r+1] := (a[g]*V[1,r]+P[r])/a[g] ;
            cum_V[r+1] := cum_V[r] + V[1,r+1] ;
            IF cum_V[r+1] > max Then
               condition := true
          end;
       ClrScr ;
       writeln ('Mixing Parameter, a',g,'=',a[g]:6:3);
       seg_vol_output ; readln;
    end;
end.
```

APPENDIX A.3

```
Program Tidal_Prism_1 ;

{ This program is a modified version of Program
Tidal_Prism (Appendix 1). The difference of the program
is that the mixing parameter is computed as a linear
function of estuary distance from the river mouth
instead of inputing constant values by users. The
program will also produce an output on the segment
volume and segment distance from river mouth for high
water and low water. However, the physical dimensions
i.e depth, width and length, and constant river
discharge are still need to be entered by users. }


Uses Crt ;

Const
     m = 2 ;
     k = 250 ;
     b = 250 ;

Var

   area, kec, w, z : array [1..m, 1..k] of real ;
   x, V, vol, cum_vol : array [1..m, 0..k] of real ;
   init, kec_a, cum_seg_x, a, cum_V, seg_x, L, P :
     array [0..b] of real ;
   q, select, g, h, n, r, i, j : integer ;
   input : char ;
   max, Rs : real ;
   condition : boolean ;



Procedure zero_value ;
begin
     For i := 1 to m do
     begin
          x[i,0] := x[i,1]+x[i,1]-x[i,2] ;
          V[i,0] := 0 ;
          vol[i,0] := 0 ;
          cum_vol[i,0] := 0 ;
        end;
     seg_x[0] := 0 ;
     cum_V[0] := 0 ;
  end;


Procedure input_vol_dim (i : integer);
begin
   j := 0;
   repeat
      j := j + 1 ;
      write ('Input DISTANCE #',j,' from river mouth (m)
```

```
               = ');
      readln (x[i,j]);
      write  ('Input DEPTH (m) at  ',x[i,j]:2:0,'m  from
                river mouth = ');
      readln (z[i,j]);
      write  ('Input WIDTH (m) at  ',x[i,j]:2:0,'m  from
                river mouth = ');
      readln (w[i,j]);
      writeln; writeln;
      write ('Any more data ? Press (Y) or (N).....');
      readln (input); writeln;
   until (input = 'n') or (input = 'N');
end;


Procedure vol_calc ;
var
   i, k : integer ;

begin
      CASE select OF

     1 : begin  {Trapizium }
         For k := 1 to j do
         begin
            w[1,k] := (w[2,k]/2)*(1 + (z[1,k]/z[2,k])) ;
            area[1,k] := (z[1,k]*w[2,k]/2)*((z[1,k] /
                           z[2,k]/2)+1) ;
            area[2,k] := 3/4*w[2,k]*z[2,k];
           end;
         For i := 1 to m do
         begin
             For n := 1 to j-1 do
             begin
                vol[i,n] := (x[i,n]-x[i,n+1])*(area[i,n]
                              + area[i,n+1])/2 ;
                cum_vol[i,n] := cum_vol[i,n-1]+vol[i,n]
               end;
            end;
         end;

     2 : begin  {Rectangle}
           For i := 1 to m do
           begin
               For n := 1 to j-1 do
               begin
                  vol[i,n] := (x[i,n]-x[i,n+1])*((z[i,n]
                                * w[i,n]) + (z[i,n+1] *
                                w[i,n+1]))/2 ;
                cum_vol[i,n] := cum_vol[i,n-1]+vol[i,n];
                end;
             end;
           end;
    end;
```

```
end;


Procedure vol_output;
begin
     writeln ('x(m)':12,'w(m)':12,'z(m)':12,'vol(m3)'
                :12,'cum_vol (m3)':15);
     For i := 1 to m do
     begin
          For n := 1 to j do
          begin
               writeln (x[i,n]:12:0,w[i,n]:12:0,z[i,n]
                         :12:1,vol[i,n-1]:12:1,
                         cum_vol[i,n-1]:15:1);
             end;
          writeln; writeln;
          readln ;
        end;
end;


Procedure gradient_calc ;
begin
     For i := 1 to j-1 do
     begin
        kec[1,i] := (cum_vol[1,i]-cum_vol[1,i-1]) /
                      (x[1,i]-x[1,i-1]) ;
        kec[2,i] := (cum_vol[2,i]-cum_vol[2,i-1]) /
                      (x[2,i]-x[2,i-1]) ;
        end;
   end;


Procedure repeat_input_mix_para ;
var
   flag_a : boolean ;
   input_a : char ;
         k : integer ;
Begin
    q := 0 ;
    flag_a := false ;
    WHILE flag_a <> true DO
    begin
         q := q + 1 ;
         write ('Input INITIAL value of mixing
                  parameter, a',q,' = ');
         readln (init[q]);
         kec_a[q] := (init[q] - 0)/(x[1,1] - x[1,j]) ;
         writeln; writeln;
         write ('Any more varies Initial mixing
                  parameter ? (Y/N)..');
```

```
         readln (input_a);
         writeln;
         IF (input_a='n') OR (input_a='N') THEN
            flag_a := true ;
      end;
      For k := 1 to q do
        writeln ('kec_a[',k,'] = ',kec_a[k]:12:8);
        readln;
end;


Procedure seg_vol_calc (i : integer) ;
var
   j, n : integer ;
   flag1, flag : boolean ;

begin
     n := -1 ;
     flag := false ;
     While flag <> true do
     begin
          n := n + 1 ;
          IF (V[1,i] > cum_vol[1,n]) AND
               (V[1,i] < cum_vol[1,n+1]) Then
          begin
               seg_x[i] := V[1,i]/kec[1,n+1] ;
               V[2,i] := kec[2,n+1]*seg_x[i] ;
               P[i] := V[2,i] - V[1,i];
               j := -1 ;
               flag1 := false ;
               While flag1 <> true do
               begin
                 j := j + 1 ;
                 IF (cum_V[i] > cum_vol[1,j]) AND
                      (cum_V[i] < cum_vol[1,j+1]) Then
                 begin
                    cum_seg_x[i] :=cum_V[i]/kec[1,n+1];
                    flag1 := true ;
                   end;
                end;
               IF i=1 Then
                  L[i] := x[1,1]
               else
                  L[i]:= x[1,1] + cum_seg_x[i] ;
               flag := true ;
            end;
       end;
end;


Procedure seg_vol_output ;
var
    t : integer ;
```

```
begin
   writeln ('sg#':3,'V(m3)':12,'LW_csv':12,'(a)value':12,
              'P (m3)':12,'X (m)':12,'L (m)':12);
   For t := 1 to r do
   begin
       a[1] := init[i];
       writeln (t:3,' ':2,V[1,t]:10,' ':2,cum_V[t]:10,'
             ':2,a[t]:10,' ':2,P[t]:10,' ':2,
                 cum_seg_x[t]:10,' ':2,L[t]:10);
       IF (t = 22)or(t=46)or(t=70)or(t=94)or(t=118) Then
       begin
          readln ;
          ClrScr;
         end;
     end;
end;


BEGIN { main }
    ClrScr ;
    writeln  ('Enter Dimension Along Estuary During  LOW
                WATER');
    writeln ;
    input_vol_dim (1);
    writeln ;
    ClrScr ;
    writeln ('Enter Dimension Along Estuary During  HIGH
               WATER ...');
    writeln ;
    input_vol_dim (2);
    writeln ;
    ClrScr ;
    Gotoxy(1,5);
    write ('Input River Discharge per Tidal Cycle, Rs. =
             ');
    readln (Rs) ;
    writeln; writeln;
    writeln ('Select Shape of Estuaty Cross Section Area
              :');
    writeln ;
    write ('     (1)-Trapizium       (2)-Rectangle
            ? .....   ');
    readln (select) ;
    writeln; writeln;
    repeat_input_mix_para ;
    ClrScr ;
    zero_value ;
    vol_calc ;
    vol_output ;
    gradient_calc ;
    max := cum_vol[1,j-1] ;
    For i := 1 to q Do
```

```
     begin
          r := 1 ;
          V[1,r] := Rs ;
          cum_V[r] := V[1,r] ;
          seg_vol_calc (r) ;
          V[1,r+1] := P[r] / init[i] ;
          cum_V[r+1] := cum_V[r] + V[1,r+1] ;
          condition := false ;
          j := 0;
          While condition <> true do
          begin
               j := j + 1 ;
               r := r + 1 ;
               seg_vol_calc (r);
               a[r] := (kec_a[r]*(L[r] - x[1,1])) +
                         init[i] ;
               V[1,r+1] := (a[r]*V[1,r]+P[r])/a[r] ;
               cum_V[r+1] := cum_V[r] + V[1,r+1] ;
               IF cum_V[r+1] > max Then
                  condition := true
            end;
         ClrScr ;
         writeln ('Initial mixing parameter = ',
                    init[i]:6:3);
         seg_vol_output ;
         readln;
     end;
end.
```