# Study on Salinity Intrusion in the Red River Delta

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Key words: Red river, salinity intrusion, numerical model, freshwater intake, harmonic analysis.

**Abstract**

Characteristics of salinity intrusion into the estuaries of the Red River System, Vietnam is studied based on many year measurement data of salinity concentration at stations along the estuaries and on a numerical model. Computed results of salinity concentration at measurement stations along rivers by the numerical model agree satisfactorily with the observation. It was found that in the dry season, the salinity intrusion length may be up to 20 km for the main river and more than 20 km for some tributaries. In the main river and tributaries with high freshwater discharge, the maximum salinity intrusion is observed in January while for the tributaries with low freshwater discharge, the maximum salinity intrusion is observed in March.

## 1 Introduction

The Lower Red River Delta (Figure 1) is the most important part of the Bacbo Delta, the main agricultural production supplier for the North of Vietnam. The hydrological regime in this area has two distinguished season: the rainy season from May to October and the dry season from November to April of the next year. The difference in freshwater discharge between the two seasons is very large. The largest monthly average freshwater discharge in August is about ten times larger than the smallest one in March. In the rainy season, due to large freshwater discharge from the upstream, the salinity intrusion problem does not present. However, in the dry season, due to small freshwater discharge, the salinity intrusion into river estuaries has been a main environmental problem here. In fact, due to relatively large slope of the river bed in this area, the salinity intrusion here is not as serious as that in the Mekong River Delta in the South of Vietnam. However the Lower Red River Delta is the most densely populated area in Vietnam,

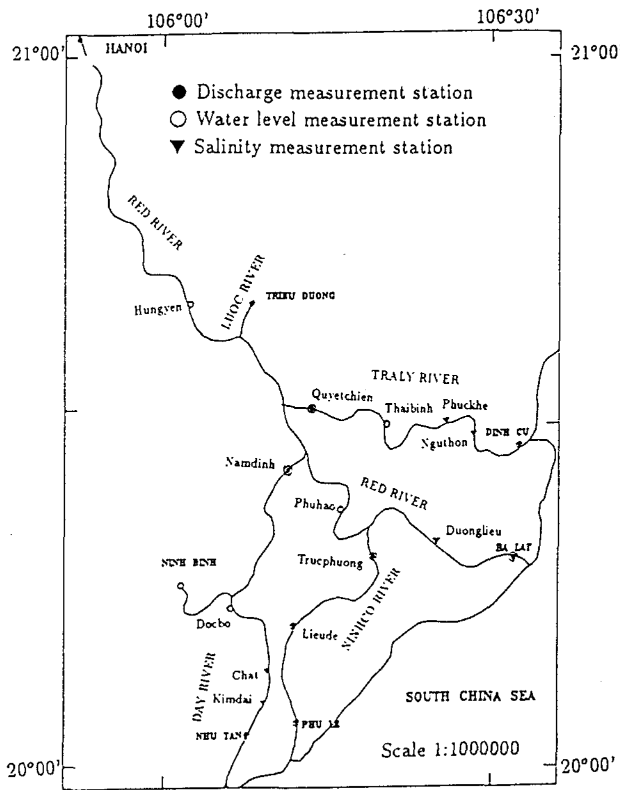

Figure 1: Red River System and Salinity Observation Stations

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and consequently the problem of salinity intrusion here is a very serious environmental problem.

Vi (1985) based on the recorded data of salinity concentration at stations along estuaries of the Red River System has draw some primary remarks on the characteristics of salinity intrusion there. Except this study, yet, there is no comprehensive study about the subject.

The aim of this study is to give a detailed view on the characteristics of salinity intrusion in the estuaries of the Red River System. Based on the many year recorded data of salinity concentration at stations along the estuaries, the regime of salinity intrusion is investigated. The details of salinity distributions along the estuaries are studied using a numerical model of the transport and dispersion of salinity.

# 2 Regime of Salinity Intrusion in the Estuaries of the System

Figure 1 depicts the estuaries of the Red River System together with locations of salinity measurement stations. The data of the salinity concentration at 10 stations have been recorded in the dry season for the period of 31 years (from 1963 up to now). However, in this study, the salinity concentration data for the period of 29 years (from 1963 to 1992) have been used for the evaluation of the regime of salinity intrusion into the estuaries of the Red River System.

Figures 2 depict the monthly average salinity concentrations at stations along the estuaries of the Red River System in the dry season. For the Day river (Figure 2a) and the Red river (Figure 2c), due to geographical conditions, the slope of the river beds near the estuaries is relatively large, and consequently the freshwater velocities in these rivers are larger than that in the Ninhco and Traly rivers; hence the decrease of salinity concentration with length from the estuaries in the Day and Red rivers is faster than that for the Ninhco and Traly rivers (Figures 2b and 2d). The maximum salinity concentration at stations along the Red and Day rivers is observed in January while that for the Ninhco and Traly Branch is observed in March.

In this study, the salinity intrusion length is defined as the length from the river mouth along the river channel to a point where the salinity concentration is 1 ppt (part per thousand). Based on the data collected in some special projects (Vi, 1985) and the recorded data at stations, a map of salinity intrusion length in the dry season has been constructed (Figure 3). As seen in this figure, in fact the salinity concentration at a location in the area depends mainly on the distance from it to the shoreline. Thus even the Ninhco river is relatively long, the distance from its upper reach to the sea is not large and almost whole this river is suffered from salinity intrusion. It has been observed that the Lieude station, which is about 23 km from the sea along the river channel, the average salinity in January is 1.976 ppt. Hence the salinity intrusion problem is still serious in this place. In fact the whole area surrounded by Red river and Ninhco river (Haihau and Xuanthuy districts, Hanamninh Province) is suffered from salinity intrusion. The main agricultural product of this area is rice and the affect of salinity intrusion to the rice field must be prevented.

To protect the rice field from flood and salinity intrusion, dikes have been constructed at both banks along the rivers. However, the construction of dikes can only partly improve the situation here, since intake of freshwater from the estuaries is the main source of freshwater for irrigation, and during the dry season, the intake of water from the estuaries is not possible. Also, in the coastal region of this area, the transport of salinity from deep soil layers to the surface in the dry season can pollute the surface soil layer if there's not enough freshwater to wash the salt out. Thus some proper measures should be proposed to reduce or prevent the salinity intrusion into the river estuaries here.

# 3 Numerical Model

## 3.1 Governing Equations

A numerical model has been developed to study in details the salinity intrusion into the estuaries of the river system. This model is a modification of the flow and salinity intrusion model for a river network (Dac, 1985 and Ca, 1990). The governing equations of the model are

Continuity equation

$$b\frac{\partial H}{\partial t} + \frac{\partial Q}{\partial x} = q, \tag{1}$$

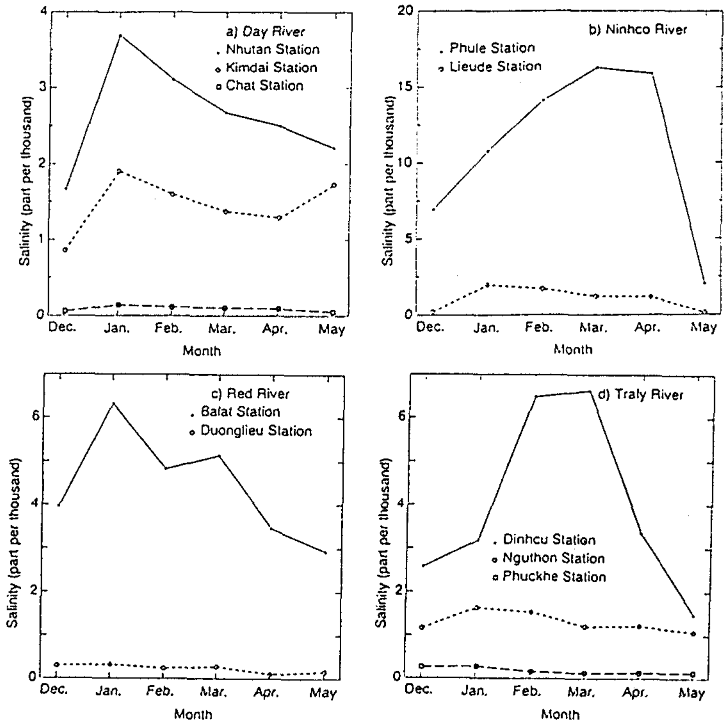



Figure 2: Monthly Average Salinity Concentration at Stations in Dry Season

Momentum Equation

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial H}{\partial x} + \frac{g \mid Q \mid Q}{A^2C^2R} = 0, \tag{2}$$

Salt transport and dispersion equation

$$\frac{\partial (AS)}{\partial t} + \frac{\partial (QS)}{\partial x} - \frac{\partial}{\partial x}\left(AD_x\frac{\partial S}{\partial x}\right) = G(S). \tag{3}$$

Where $H$ is the water level, $Q$ the river discharge, $b$ the river width at the water surface, $A$ is the cross-sectional area of the river, $C$ the Chezy coefficient, $g$ gravitational acceleration, $R$ the average hydraulic radius of the river at the cross-section, $q$ the lateral flow into the river, $S$ the salinity concentration, $D_x$ the apparent longitudinal dispersion coefficient of salinity and $G(S)$ the source or sink of salinity due to lateral flow.

Strictly speaking, the system of Equations (1-3) can be applied only for well mixed estuaries. In fact, with the slope of the river bed in the range of $2\text{x}10^{-5}$ to $5\text{x}10-5$ and freshwater velocity in the range of 0.1 m/s, compared with the maximum tidal velocity up to 2 m/s, the estuaries in the Red River System in the dry season can be considered well mixed near the river mouth and the stratification is increasing towards upstream (Ca, 1990). However, due to strong tidal effect in this area, the stratification degree is rather small and the simulated results in the next section show that it is save to apply the system of Equation (1-3) to the river estuaries.

## 3.2 Numerical Scheme

The numerical scheme for the integration of the system of Equations (1-3) is the improvement of

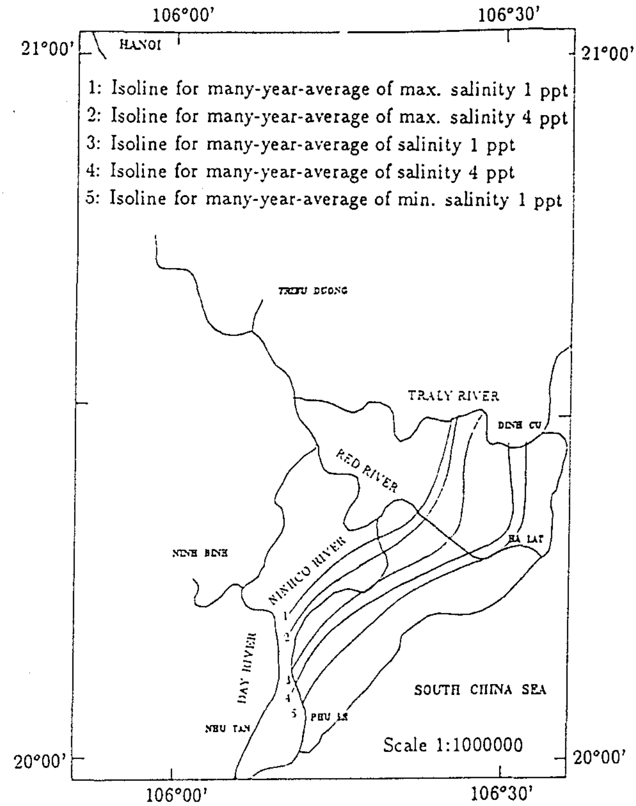


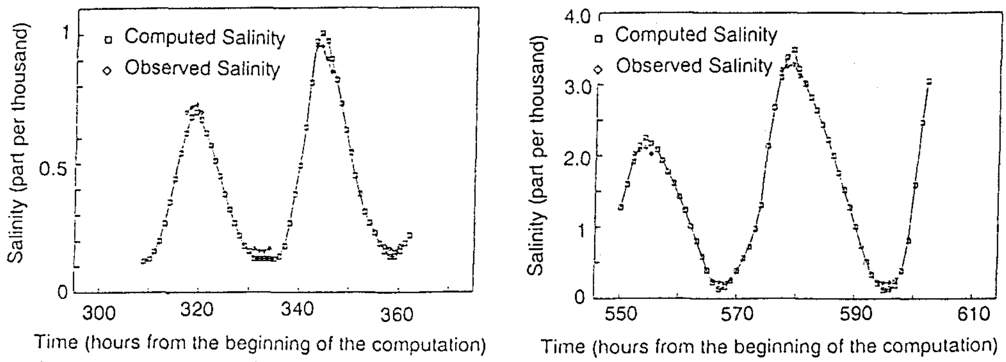

Figure 3: Contourlines of Average Salinity Concentration in the Dry Season in the Lower Red River Delta (ppt is the abbreviation of part per thousand

that of Dac (1985) and Ca (1990). The river network is divided into branches, linked at river junctions. A control volume, staggered grid scheme (Patankar, 1980) is applied for the integration of the system of Equations (1-3) in an individual branch. The branch is divided into segments with finite length $\Delta x$. The water discharge $Q$ and salinity concentration $S$ are computed at the center of the segment and the water elevation is computed at its ends. A first order upwind scheme is used for the convection terms in Equations (2) and (3). Central difference formulas are used for the salinity dispersion-diffusion term in Equation (3). Since control volume scheme is used, there's no solutions for the water discharge and salinity concentration at the ends of the branch. Thus, additional segments with zero thickness (Patankar, 1980) is added to the ends of the branch and the solutions of water discharge and salinity concentration can be determined there. At the river junction, the condition of mass and momentum conservations requires that the flux of water towards the junction must equal the ones leaving it; and the solutions for water level and salinity concentration must have unique values there disregarding they are computed from the discretized equations for any of the branches joining the junction.

An implicit scheme similar to the well known Crank-Nicholson scheme is used for the time. However, in this model the implicit factor, which is the weighting factor for the values of unknowns at the new time step is taken as 0.667 instead of 0.5 of the Crank-Nicholson scheme.

The above mentioned scheme can produced a tridiagonal matrix for the unknowns for each branch. By the well known double-sweep algorithm, the unknowns at intermediate points inside the branch can be eliminated to get a system of equations for unknowns of water level, water discharge and salinity at junctions. This system of equations is solved using the standard Gauss elimination. Having obtained the values of unknowns at junction points, the values of unknowns at nodal points inside a branch can be readily obtained by the Thomas algorithm.

Since Equation (2) is nonlinear in term of the unknown water discharge $Q$, an iterative procedure is used for solving the system of Equations (1) and (2). The solutions of Equations (1) and (2) then can be used for the integration of Equation (3).




a) Phuckhe Station (14-15 March, 1980)    b) Kimdai Station (24-25 March, 1980)

Figure 4: Computed and Observed Salinity Concentration

The boundary conditions for the computation are given water discharge at the upstream boundary points, say, at Hanoi station on the Red river and Trieuduong stations on the Luoc river. At Ninhbinh station on the Day river, since there's no available data of water discharge, the boundary conditions at this point and all estuarine boundary points: Nhutan station on the Day river, Phule station on the Ninhco river, Balat station on the Red river and Dinhcu station on the Traly river, are given water elevation. In fact, the main source of freshwater in the Day river come from the Red river through the river branch at Namdinh; and in the upper reach of the Day river at Ninhbinh station, the freshwater discharge from upstream is extremely low, and consequently the tidal action is still very strong there. Thus even the Ninhbinh station is a upstream boundary point, it is safe to use the water level as the given boundary conditions. The boundary conditions for salinity computations are given salinity concentration at the estuarine boundary points and zero value of salinity at the upstream boundary points.

### 3.3 Results of Computations and Discussions

The numerical model is used to simulate the salinity intrusion into the river estuaries in March, 1980. The recorded data of water level, discharge and salinity at stations inside the river system was used for calibration and verification of the model. The Chezy coefficient $C$ and apparent longitudinal dispersion coefficient $D_x$ are determined from the calibration for each river segment. Their values for different river segments are different, but generally, the Chezy coefficient $C$ is in the range 65 to 75 $m^{1/2}/s$ and longitudinal dispersion coefficient $D_x$ is in the range 800 to 1000 $m^2/s$.

Figures 4 depict examples of the comparisons between the computed and observed salinity concentration at Lieude station on the Ninhco river and Duonglieu station on the Red river. Figures 5 depict the same comparisons, but for water level at Hungyen station on the Red river and Thaibinh station on the Traly river. As seen, the model can simulate the real dynamical processes and salinity intrusion picture with satisfactory agreement. Results of the computations for other days (not shown) also confirm this remark. Thus, the results of the computations reveal that the assumption of well mixed estuaries can be applied with satisfactory accuracy.

Using the model, details of salinity intrusion into the estuaries of the river system can be investigated. It is found that during the flood tide in the time of spring tide, the contour line of 1 ppt salinity concentration can cover nearly all the Ninhco river while during the time of ebb tide, this line retreats farther than Lieude station. However, during the ebb tide, due to low water level in the rivers, the intake of water for irrigation is difficult. At the time of moderate tide, the salinity intrusion length during flood tide is smaller than that for the spring tide. However, within one tidal period, it is possible to find a time when the salinity concentration near the junction between the Red river and the Ninhco river becomes near zero while the water level in the river is sufficient for freshwater intake by opening some sluice gates in this area. Thus, if the tide and the salinity concentration can be forecast in the river system, the intake of freshwater for irrigation can be managed.

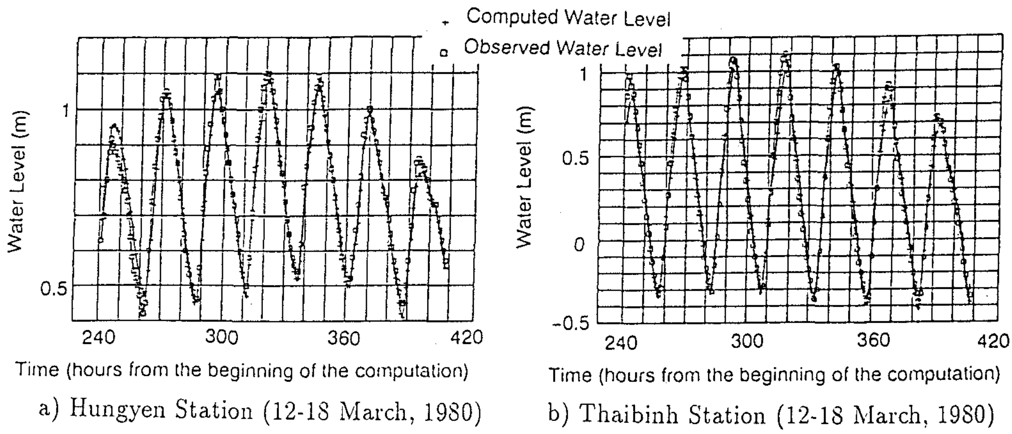



Figure 5: Computed and Observed Water Level

The salinity intrusion length is shortest for the Day river, where the maximum salinity intrusion length is less than 20 km, while for the Red river and Traly river, the salinity intrusion length is of the order of 20 km.

Harmonic analysis has long been proved an efficient and convenient method for the tidal prediction with reasonable accuracy. From the pattern of daily variation of salinity concentration in Figures 4, it is remarked that the salinity intrusion has a strong relationship with tide. To study the effect of tide on the salinity intrusion, and also the possibility of using harmonic analysis to predict the salinity concentration along the estuaries of the river system, the numerical model had been used to generate the data at a number of points along the estuaries where the measurement data of salinity are not available. The generated data of salinity concentration were then used for harmonic analysis to obtain the values of harmonic constants of the four main tidal components $M_2$, $S_2$, $O_1$ and $K_1$, the principle Lunar component, principle Solar component, large Lunar declinational component and Luni-Solar declinational component of tide, respectively for salinity. The computed results (not shown) showed that daily variation of water level and salinity at points along the estuaries can be predicted with reasonable accuracy using harmonic constants of the four tidal components. Thus, it is possible that using the harmonic constants, the intake of the freshwater for irrigation in the lower Red river delta can be managed efficiently.

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