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A Method for forcasting Salinity Process in Seawater-Intruded Rivers

A METHOD FOR FORCASTING SALINITY PROCESS IN SEAWATER-INTRUDED RIVERS

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ABSTRACT

During the period in dry seasons when seawater intrudes into the river network of Pearl River Delta, it is necessary to forecast the salinity process at water intakes so as to prevent salt water being taken. The stochastic method currently used for salinity process forecasting provides only the relationship between flow from upstream and daily averaged hours when salinity excesses standard, taking the lunar tide cycle as stochastic period. Based on the study how tide, upstream flow and wind influence the salinity process, a number of functions are chosen to simulate these influences. With these functions an integrated model is constructed to forecast salinity process. This method has been applied to water intakes in Modaomen Waterway and demonstrated to be simple but reliable.

1. INTRODUCTION

It is a normal phenomenon that seawater mixes with fresh water in estuarine area. In flood seasons the saline boundary, defined as the interface between "freshwater" and "salt water" where salinity is 2.5‰, usually is pushed out of the estuary, while in dry seasons the saline boundary normally intrudes into somewhere of the river, depending on the dynamic and morphological characters of the estuary (Savenijie, 2005; Duc, 2008). In dry seasons, the saline boundary would move up and down in the river course following tidal movement, and during this process salinity in each spatial point of the river course would change temporally. The upmost point where the saline boundary could reach in a year depends essentially on the minimum flow from upstream of the river in the year, and of course also the combination of the follow and the tide. Obviously, the upmost point where the saline boundary could reach would fluctuate every year due to that the minimum flows in dry seasons and its combination with the tide would change every year. In normal cases, the average of the upmost point where the saline boundary could reach should gradually move towards downstream because the river mouth would grow towards the sea due to sedimentation.

However, since 1990's the average of the upmost point where the saline boundary could reach in the Pearl River Estuary have shown the tendency to continuously move towards upstream. This could be because the minimum flow in dry seasons from upstream of the river decreased comparing those in the history, and because sand digging in the river course deepened the waterway. Due to this

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unusual salt water intrusion into the upper river network of Pearl River Delta, a number of water intakes for drinking water supply are threatened in dry seasons. Therefore it is necessary to forecast the salinity process at water intakes so as to prevent salt water being taken. In view that existing methods for salinity forecasting cannot meet the needs, this paper reports a method particularly developed for forecasting salinity process in seawater-intruded rivers.

2. EXSISTING METHODS

There exist three kinds of method that have been used for salinity process forecasting in seawater-intruded rivers. The first one that people can easily imagine is numerical modeling. In fact, there are several difficulties in using numerical models to predict the salinity process. The main difficulty is that the basic rule of numerical modeling requires that simulated results and the driving boundary conditions be simultaneous, while we always have difficulties to determine in advance the real driving boundary conditions for a numerical model, therefore even the "real" boundary conditions for the model could not be forecasted, naturally the "really" happened process could not be forecasted by using the model.

Another method is theoretical analysis. This method were originated by Ippen and Harlemen (1961) and then extended by Prandle (1981), Savenijie (1993), Nguyen (2006), Brockway et al (2006) and Song (2008). Theoretical methods employ one dimensional mass conservation equation to salt in the river, and in the meantime treat the river course as a continuous function. Based on this a one dimensional analytical solution is obtained for salinity distribution along the river course. In most cases, because this solution is obtained at some particular instant of tidal process, it is a constant result and not a temporary function. Therefore it cannot be used for forecasting salinity process at arbitrarily selected spatial point in the river.

Most frequently used method for salinity forecasting is stochastic technique. This includes regression analysis of multi-factors (Liu et al, 2007), BP neural network analysis and so on (Wen et al, 2007). The stochastic technique can establish relationship among relevant parameters. The most useful and practically used relationship can determine average hours in a day during which salinity at any selected water intake or gate exceed standard limit under given flow from upstream. The typical stochastic period is a lunar tidal period. Again, the above obtained stochastic relationship is not a temporarily continuous function. With this relationship one is not able to know exactly from when to when the salinity at the concerned point would exceed the standard limit.

In view of above-mentioned situation, it is indeed necessary to seek a new method for salinity process forecasting.

3. SALINITY PROCESS OBSERVATIONS

As is previously mentioned, salinity process in a seawater-intruded river mainly depends on tidal process and fresh water flow from upstream of the river. In order to understand how these principal factors influence the salinity process so as to develop a reliable method for salinity process forecasting, a large amount observations were conducted in the past decade in the Pearl River Delta region. Some particularly designed and detailed observations were conducted in Modaomen Waterway that is a main stream in the river network with some major water intakes.

Figure1 shows a salinity process comparing with the tidal process at a water intake in Modaomen Waterway in a period covering two and half months between November 2009 and January 2010. One can easily find from the figure that the salinity changes periodically with periodical change of the tidal level in the lunar cycle. Furthermore, the salinity always reaches its peak values 3-4 days earlier than the tidal level. The valleys are also the case. Mechanism of this phenomenon has partly been discussed somewhere else (Chen et al, 2011).

Figure 2 shows the relationship between salinity and tidal level in a daily change. It is seen that no matter in surface layer or bottom layer, the peaks and valleys of the salinity are essentially follow the peaks and valleys of the tidal level, but with a phase difference of 0.5 to 2.5 hours behind. This is because water flow is driven by tidal level and changes of flow therefore lags changes of tidal level, while changes of salinity depends on changes of flow so finally changes of salinity lag changes of the tidal level. It can be imagine that the time period of the lag depends on the location of a spatial point, tidal pattern and its combination with upstream flow, wind, etc.

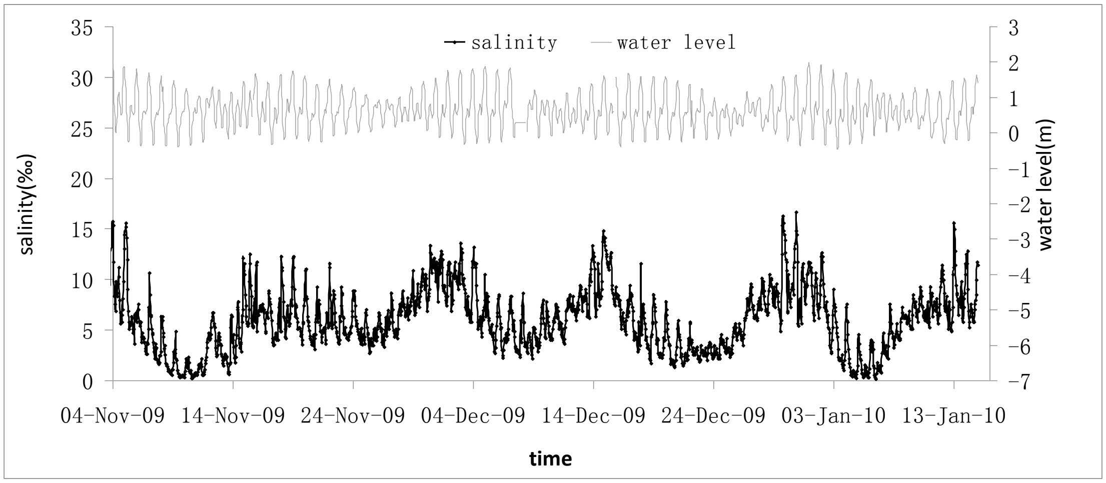

Figure 1 Relationship between salinity and tidal water level in lunar tidal cycles.

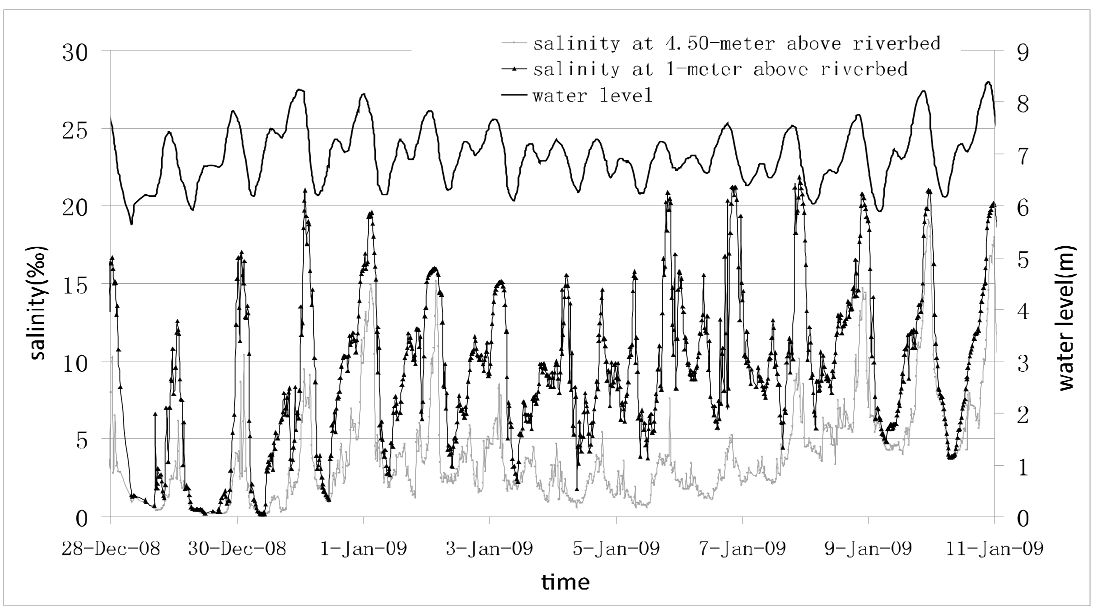

Figure 2 Relationship between salinity and tidal water level in daily tidal cycles.

Fresh water flow from upstream of the river is the basic factor determining the maximum concentration of salt in the river course. Figure 3 is a stochastic result showing relationship between flow from upstream of the river, Q, and upmost location of saline boundary in the river network of the Pearl River Delta. It is seen that the effect of flow from upstream is most significant in Modaomen Waterway.

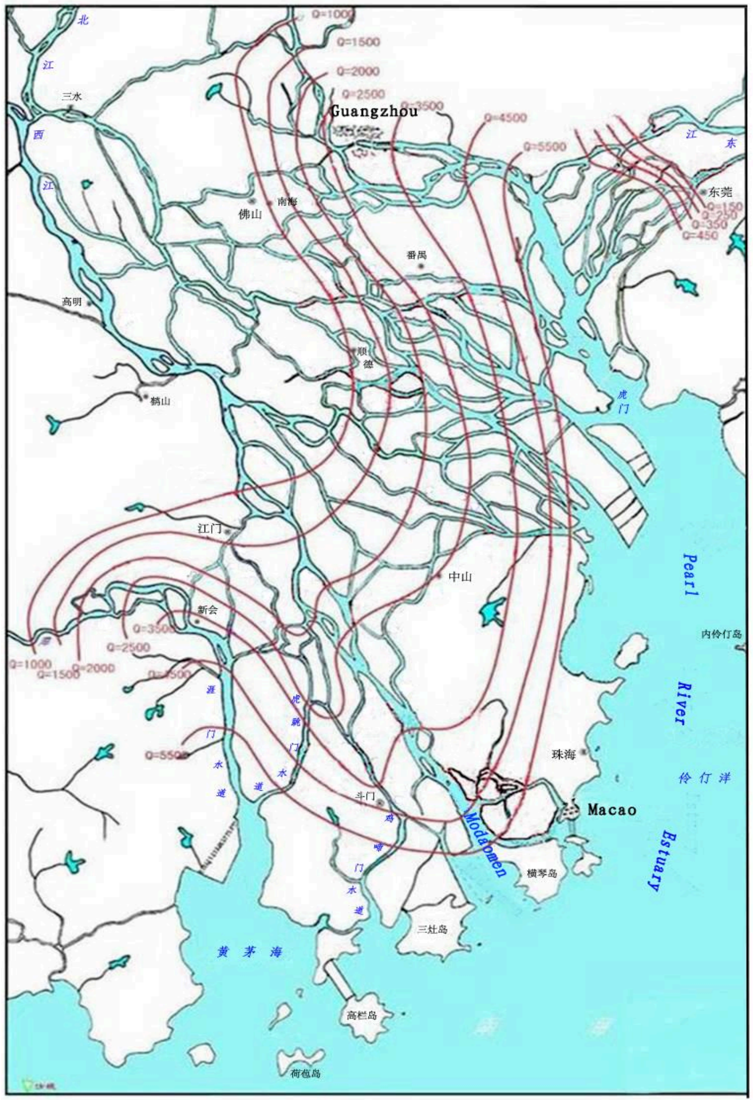

Figure 3 Relationship between saline boundary and fresh water flow from upstream.

4. CONSTRUCTION OF THE MODEL

Observations given in the previous section and by others indicate that salinity at any point in a seawater-intruded river is mostly directly proportional to tidal water level and inversely proportional to flow from upstream of the river, and that the salinity process has an evolution cycle following the lunar tidal cycle. It is also found that wind has significant influence on the salinity process. In view of this, a number of functions are chosen to simulate above-mentioned influences of factors. With these functions an integrated model is constructed for forecasting salinity process, as is shown in equation (1)

$$S_A(t) = S_o f_1(t) \cdot f_2(t) \cdot f_3(t) \quad (1)$$

where, $S_A(t)$ is the salinity at a concerned point (such as the water intake A) in the waterway at the time, t; S_o is a constant to be determined by the observed salinity in a short period at the concerned point; and

$$f_1(t) = (\frac{Q_0}{Q})^{\alpha} \tag{2}$$

in above equation, Q_0 and α are constants, Q is the fresh water flow from upstream that can be determined or observed few days in advance. $f_2(t)$ is the daily tidal process, but with a lag of phase, in the sea area near the river mouth. It is usually known a year in advance. In fact $f_2(t)$ is a dimensionless tidal water level with modification due to wind effect. Wind effect is expressed by following equation:

$$H_w = \frac{u_w}{u_o}\cos\gamma \tag{3}$$

here H_w is a modification to tidal water level, u_w is the wind speed and u_o is a constant, γ is the angle of wind direction to the river longitudinal axis towards upstream. Obviously, involvement wind effect in salinity process forecasting relies on reliable meteorological forecasting. $f_3(t)$ describes influence of tidal pattern change in the lunar cycle,

$$f_3(t) = [1 + b\cos\sigma(t+\phi)] \tag{4}$$

here, σ is frequency of the lunar cycle, and ϕ is the phase difference between the tide and the salinity process in a lunar cycle, b is a constant.

5. APPLICATION

This method has been applied to salinity process forecasting at water intakes in Modaomen Waterway. Figure 4 shows an example of comparison between forecasted and later observed salinity process at Water Intake 1 and Water Intake 2 in three lunar tidal cycles. It is seen that the agreement between the results forecasted and later observed is acceptable, and the forecasted results can help planning of the water intake operation in advance.

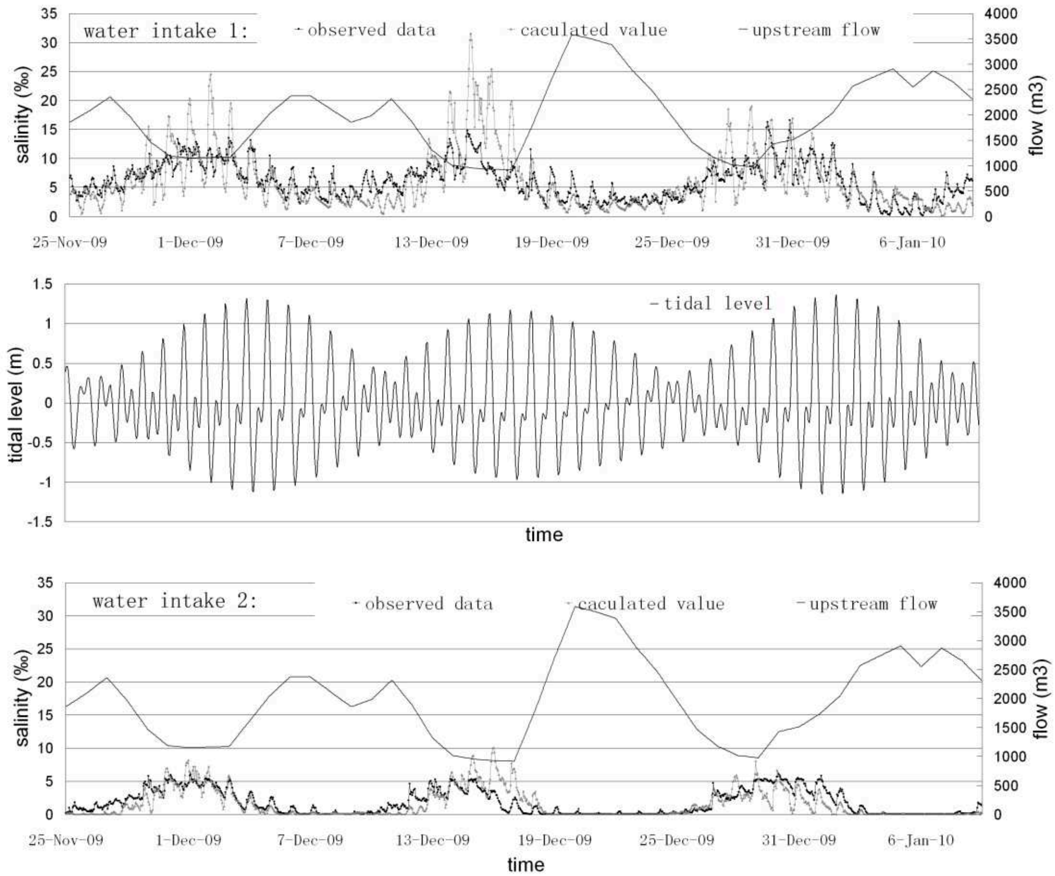

Figure 4 Comparison between forecasted and later observed salinity process at Water Intake 1 and 2.

6. CONCLUSION REMARKS

Repeated applications have demonstrated that the constructed model suggested in this paper is a simple but reliable method. In one hand, since the method involves real driving conditions such as upstream flow, tide, wind etc., the forecasted salinity process usually well agrees with the real process; on the other hand, the method does not involve much complicated calculation as numerical modeling. In addition, number of the involved constants can be determined for deferent river courses and deferent time period, allowing the method to be easily applied to respective river courses.

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