

題 目

Salt Flux, Salinity Intrusion and Estuarine Circulation in the Ota Diversion Channel  
(太田川放水路における塩分フラックス, 塩水遡上とエスチャリー循環に関する研究)

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The large salinity variation in estuaries may create a challenging environment for the ecological system. Changes in the balance between freshwater and saltwater can lead to the loss of species. Therefore, investigation of salinity intrusion in estuaries is important, both in terms of understanding the complex balance between the fluvial and tidal processes that affect the salinity intrusion within the estuary, and also in terms of formulating effective policies for sustainable development in coastal regions. Understanding the mechanisms that affect the salinity intrusion has implications for management of estuaries. A clear understanding of the factors affecting the salinity intrusion in estuaries is thus required for the long-time period of hydrological conditions.

The Ota Estuary encompasses the branched section of the Old Ota River and the Ota Diversion Channel about 9 km upstream from the estuary mouth. The present study attempts to identify the salinity intrusion through the Ota Diversion Channel that is a shallow tidally-dominated channel with gates. The existence of the Gion Gates at the upstream border which restricts the freshwater runoff is an important feature of Ota Diversion Channel. This study consists of the field observations and numerical simulations. This thesis addresses the variability of salinity flux, flushing time, salinity intrusion length, stratification and estuarine circulation in the Ota Diversion Channel under the different estuarine forces (freshwater, tides, etc.).

Near the upstream border of the Ota Diversion Channel (Gion Station), the long-term salinity and flow velocity data are collected using an innovative instrument which is called Fluvial Acoustic Tomography System (FATS). FATS data provides novel information about seasonal and annual variability of salinity and flow rate in this region. The long-term salinity and flow rate variations at the Gion Station are analyzed over the period between 2009 and 2013. The salinity variations show a correlation with seasonal variations of the mean sea level, winds and freshwater runoff. Furthermore, spring-neap tidal cycles significantly influence the salinity variations due to differences in tidal mixing. The larger tidal range during the spring tides constricted the saltwater intrusion.

The flushing time in the Ota Diversion Channel is estimated using a practical method based on the FATS data. The average flushing time is estimated about 1.8 days under mean flow conditions. This result indicates that the flushing time is considerably short compared to other estuaries. Moreover, the transition time from highly stratified to partially-mixed is a few days. This study indicates that the flushing time is controlled by the advection process at the Ota Diversion channel. The maximum flushing time in the Ota Diversion Channel is usually occurred when the freshwater discharge is low and the mean sea level is reached the highest levels.

In this study the salinity variations at the two main branches are investigated. The results suggest that the variability of salinity at both branches is significantly different. This difference is mainly caused due to the condition of both gates.

In addition, a three-dimensional numerical model (EFDC) is used to simulate water level, salinity and

flow rate in the Ota Diversion Channel. Several field observations through the Ota Diversion Channel were carried out for validation and calibration purposes. The numerical experiments are carried out to: 1) estimate the longitudinal distribution of salinity and velocity at the Ota Diversion Channel. 2) clarify the dominated salinity transport mechanisms and salinity balance in the Ota Diversion Channel during spring-neap tidal cycles and wet and dry seasons. 3) investigate the variability in the estuarine circulation and stratification. 4) examine the response of the salinity intrusion to changes in the freshwater runoff and tides.

The results indicate that the longitudinal salinity gradient is around  $-1.1 \text{ km}^{-1}$  between the channel mouth and about 7 km upstream from the mouth. On the other hand, at the upstream region the salinity gradient is about  $-5 \text{ km}^{-1}$ . This result indicates that the longitudinal salinity gradient is large at the upstream border of Ota Diversion Channel compared with the other estuaries. Higher salinity gradient at the upstream region can generate stronger estuarine circulation.

To investigate the salinity transport mechanisms, the salinity flux is decomposed into three components: steady shear, advection, and tidal dispersion salt fluxes. The steady shear flux is induced by gravitational circulation and the tidal dispersion generated by temporal correlations between the salinity, water level and velocity. The advection flux is mainly induced by river discharge. The results indicate that the salinity balance is not in a steady balance during spring-neap tidal cycles. During spring tides, the total salt flux is directed seaward, and the salt exits from the estuary. In contrast, during neap tides, the total salt flux is directed landward, and the salt enters the estuary. During the spring tides, the tidal dispersion is maximized due to larger correlations between the water level, salinity and velocity. While during the neap tides the steady shear flux is increased due to higher longitudinal salinity gradient and estuarine circulation near the upstream border of Ota Diversion Channel.

The variability of tidal currents and stratification during wet and dry seasons are simulated. The amplitude of tidal velocity varies from 0.5 m/s at the strongest spring to 0.16 m/s at the weakest neap tides, respectively. The estuarine circulation and stratification at the Ota Diversion Channel is significantly varied by the changes in freshwater runoff. During the low freshwater runoff the estuarine circulation is weak, especially at the downstream sections. Then the stratification is low at the downstream sections. Meanwhile, the maximum bottom-surface salinity differences at the upstream regions are established during neap tides by the values around 20, when low vertical mixing persists for several days. During the high freshwater runoff, estuarine circulation is reinforced. The larger freshwater runoff increases the thickness of halocline at the downstream, so that the bottom-top salinity difference increases.

The relation between the salinity intrusion length and freshwater runoff is examined. During the low and moderate freshwater runoff the salinity intrusion length responding to the freshwater discharge generally follows a power law of  $-0.11$  and  $-0.14$  for the neap and spring tides, respectively. The dependence of salinity intrusion on freshwater discharge is weaker from the standard  $-1/3$  power dependence that is derived theoretically for exchange dominated estuaries. The reason for behavior is due to the existence of the Gion gates which restricts the freshwater runoff to the channel significantly. Due to the Gion gate operation the time response of tidally-averaged salinity to changes in freshwater runoff is decreased significantly. Also the result shows that the difference in salt intrusion length between springs and neaps is significant in Ota Diversion Channel. The reason is related to the influence of tidal amplitude on the salinity and flow velocity variations. The stronger vertical mixing reduces density stratification during spring tides. The higher mixing levels actually inhibit salinity advection, and salinity intrusion is stronger on neap tide.