Observations of Saline Water Intrusion at Estuaries with Salt Wedges

Isao YAKUWA, Susumu TAKAHASHI
and
Morimasa OHTANI

Abstract

Longitudinal profiles of salt wedges were observed by ultrasonic means at the estuaries of the Shiribetsu, Mogami and Teshio River. The behavior of salt wedges and also the surface salinity distribution are greatly influenced by the shape of the river bed and the fluctuations of the river discharge.

The changes of the bottom chlorinity and the movement of the interface level caused by the tide and the change of the river discharge were observed at the mouth of the Shiribetsu River from June to October, 1981 and 1982. The value of the bottom chlorinity increased from that of the fresh water to the sea water for several days in the middle of June after the flood season. The amplitude of the internal wave was 6.3 times as large as the tidal motion of the surface.

1 Introduction

At the estuaries of many rivers which pour into the Japan Sea, salt wedges penetrate

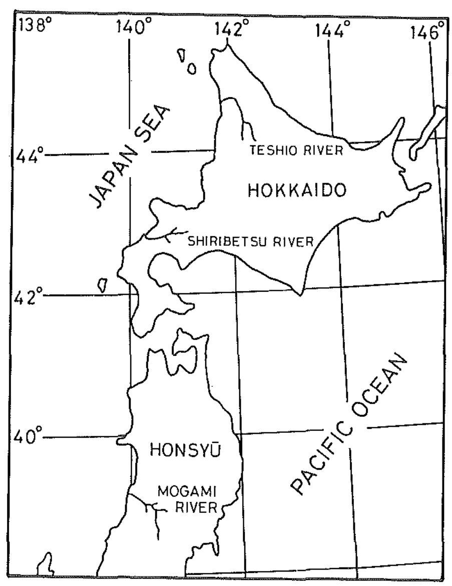
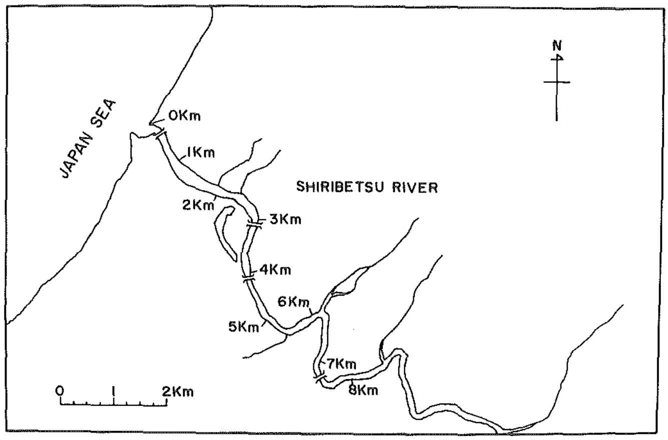


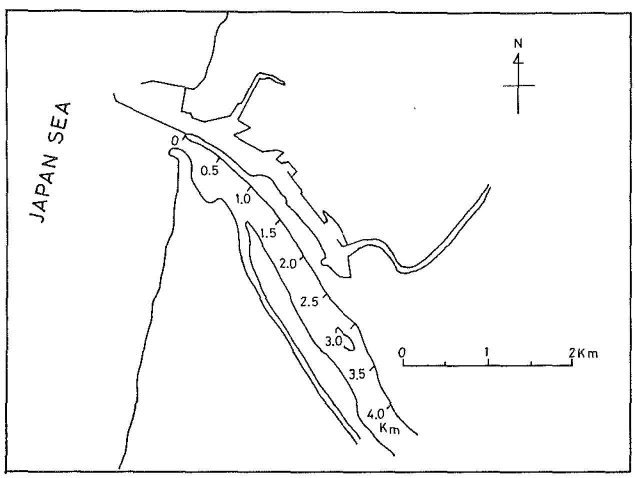
Fig. 1 Location map of Hokkaido and Tohoku District.

Department of Engineering Science, Faculty of Engineering, Hokkaido University, Sapporo 060, Japan.

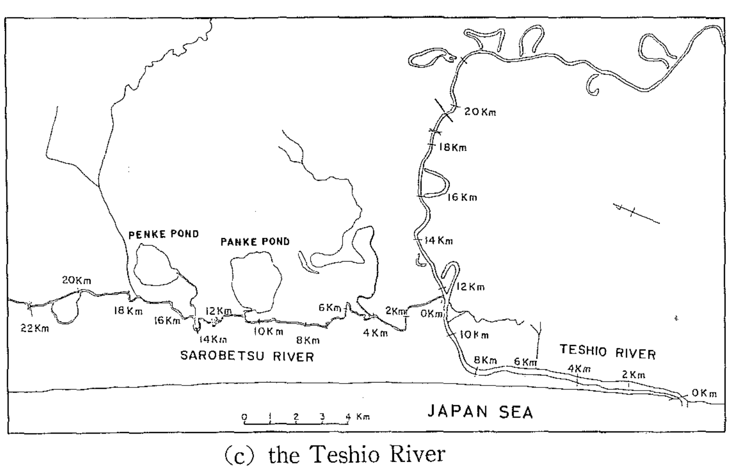
into the river mouth when the river discharge decreases below the critical value of the river. Because the Japan Sea has a small tidal range (its maximum value is about 30 cm),



(a) the Shiribetsu River



(b) the Mogami River



(c) the Teshio River

Fig. 2 Map near the estuary.

the interface of the fresh and salt water is steady except near the river mouth.

The authors have observed the longitudinal profiles of the salt wedges by the ultrasonic method[1)2)] at some estuaries mainly in Hokkaido, Japan. The behavior of the interface, as well as the shape of the bed, can be simultaneously recorded by echo-sounding from the river mouth to the front of the salt wedge. At the regions where the interface is steady, it is clearly recorded by a sharp line on the chart. On the other hand, at the unsteady

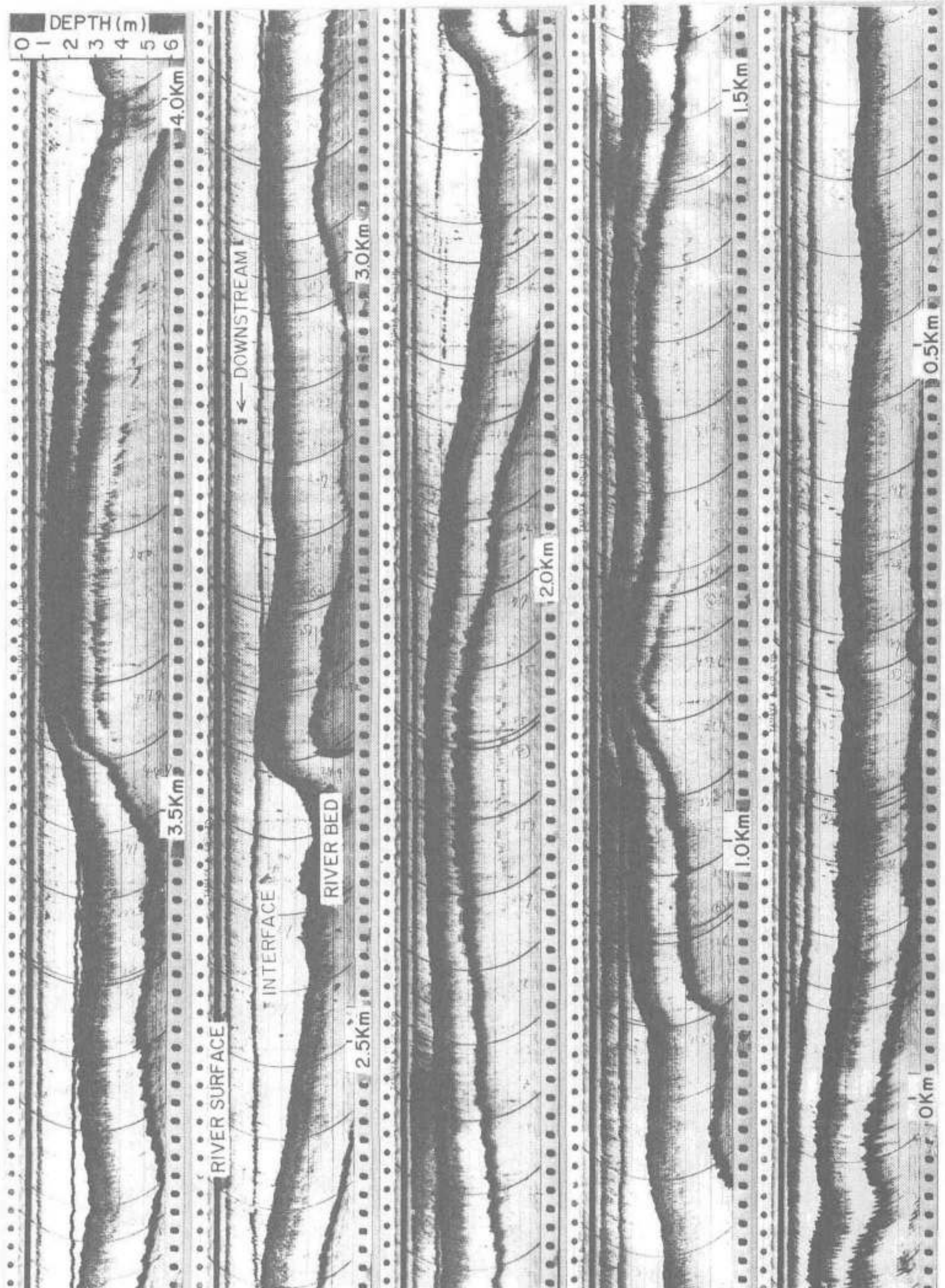


Fig. 3 A longitudinal profile of the salt wedge at the Shiribetsu River (July 23, 1977).

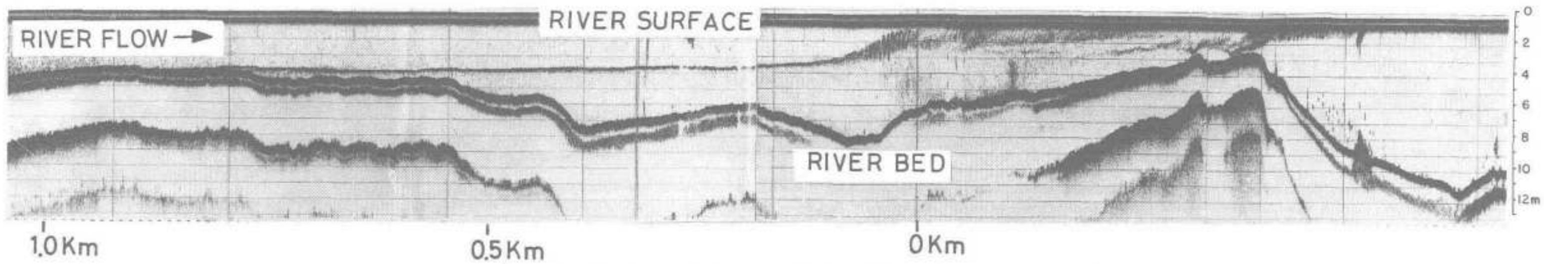
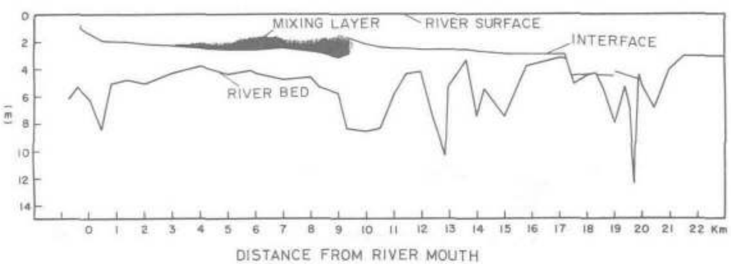
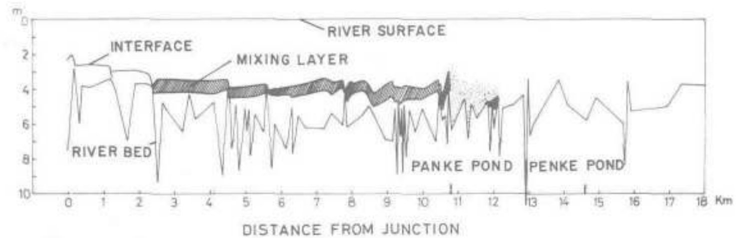


Fig. 4 A longitudinal profile of the salt wedge at the Mogami River (July 22, 1974).



(a) the Teshio River (Sept. 26, 1973)



(b) the Sarobetsu River (Sept. 26, 1973)

Fig. 5 A longitudinal profile of the salt wedge.

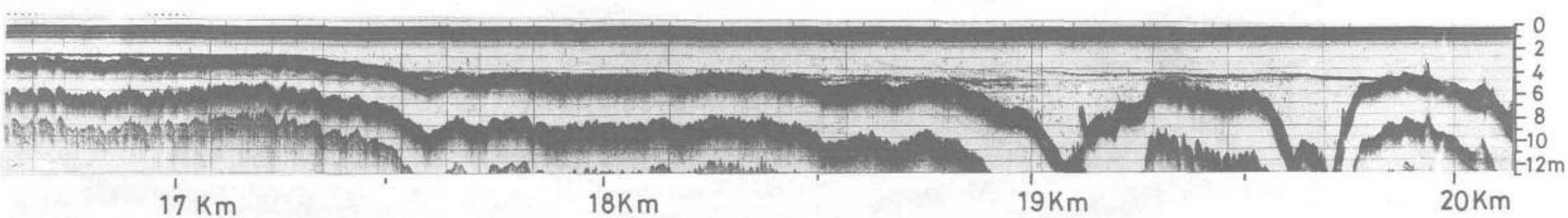


Fig. 6 A longitudinal profile near the front of the salt wedge at the Teshio River (Sept. 26, 1973).

region where the mixing of the fresh and salt water is strong, the interface is not clear and is recorded as a broad band. Especially near the river mouth, the mixing is violent and the mixing layer sometimes broadens until the river surface.

When the river discharge increases, however, the steady interface changes to an unsteady state and the salt wedge begins to decay. In such a case, a violent mixing of the fresh and salt water can be seen at all regions along the salt wedge.

We show some observational results of the behavior of the salt wedge and the saline water intrusion at the estuaries of the Shiribetsu, Mogami and Teshio River. Figures 1 and 2 show the location maps near the estuary of each river.

2 Behavior of the salt wedge

Figure 3 shows a longitudinal profile of the salt wedge observed by the ultrasonic method on July 23, 1977, at the estuary of the Shiribetsu River[3] which has a length of 130 km and a normal discharge of 60 m^3/s. Because the river discharge (27-29 m^3/s) decreased below the critical discharge (150 m^3/s), the front of the salt wedge reached 3.5 km upstream from the river mouth. Although the interface seems to be cut by the projections on the river bed at regions near the points 1.2 and 1.9 km respectively from the mouth, the salt water before and after the projection is connected with each other through the deep part of the cross section.

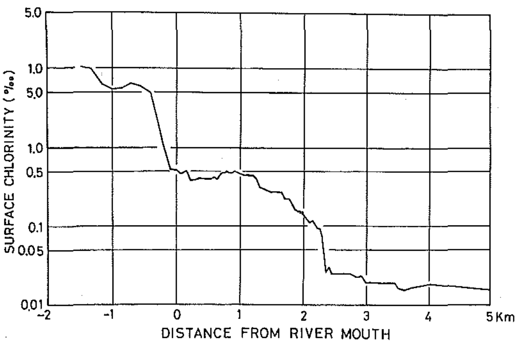
A profile of the salt wedge in the Mogami River is shown in Fig. 4. It has a length of 230 km and a normal discharge of 370 m^3/s, and the critical discharge is assumed to be about 400 m^3/s. As the river discharge was 250-270 m^3/s during the echo-sounding on July 22, 1974, the length of the salt wedge was observed as 0.87 km. Although the interface is steady in all regions along the salt wedge, a violent mixing of the fresh and salt water can be seen at a region 0∼−500 m downstream from the river mouth, where a big sand ridge is formed on the sea bottom.

At the estuary of the Teshio River which has a length of 256 km and a normal discharge of 200 m^3/s, a growth of the salt wedge influences the saline water intrusion into the Sarobetsu River[4] which joins the Teshio River at a point 11.5 km upstream from the mouth. When the observation of the salt wedge was carried out (September 26, 1973) the discharges of the Teshio and Sarobetsu River were measured as 80∼100 m^3/s and 0.6∼0.7 m^3/s respectively. The critical discharge of the Teshio River is 350 m^3/s, and the salt water begins to intrude into the Sarobetsu River when the discharge dicreases below 120 m^3/s. As shown in Fig. 5(a), the mixing is violent at the region 4∼9 km because the route of the stream is curved and the flow is turbulent there. In the Sarobetsu River, the interface is not clear as shown in Fig. 5(b) because the fresh and salt water has been mixed slowly over a long time scale. Figure 6 shows the record near the front of the salt wedge which is the same as shown in Fig. 5(a). The front of the salt wedge reaches 17.3 km where its progress is obstructed by the projection on the bed. On the other hand, the salt water penetrates into the region 17.5-19.8 km beyond the projection.

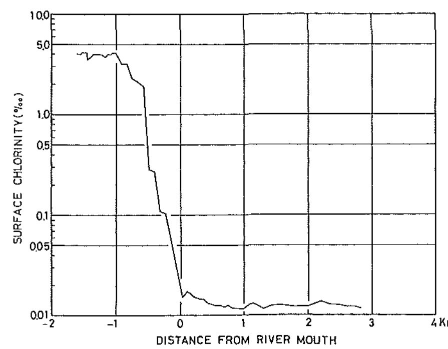
3 Distribution of the surface salinity

In order to obtain a longitudinal distribution of the surface salinity, we sampled 200∼300 cc of the surface water continuously every 30 s during echo-sounding and measured chlorinity in the water[5]. Figure 7 shows longitudinal distributions of surface chlorinity at estuaries of the Shiribetsu, Mogami, Teshio and Sarobetsu River. The value of chlorinity increases downstream from the point where the front of the salt wedge is found and the gradient of chlorinity-distance curve steeply increases near the river mouth, showing that the mixing is extremely violent there.

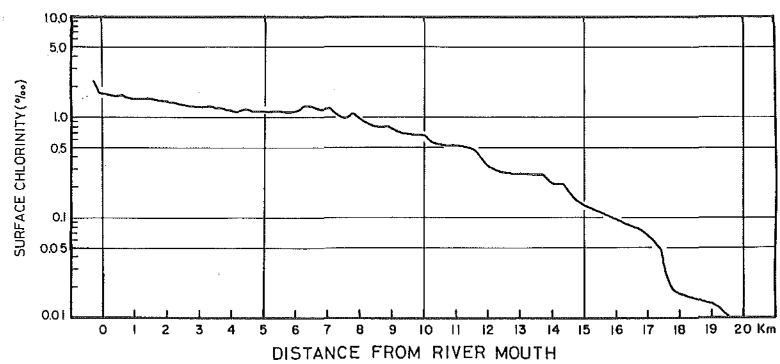
From Fig. 7(a), it can be seen that the curve of the Shiribetsu River has three stages, −1∼0, 0∼2.3 and 2.3∼5.0 km. At the region near the point 1.9 km, the mixing is strengthened as well as at the river mouth, because a big projection on the bed obstructs the flow. In the case of the Mogami River shown in Fig. 7(b), chlorinity keeps the



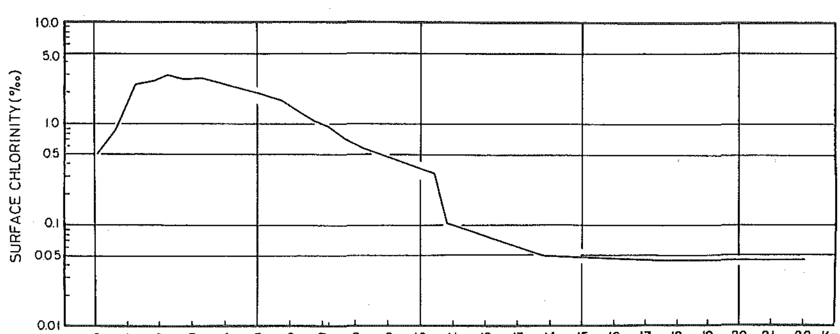
(a) the Shiribetsu River (July 23, 1977)



(b) the Mogami River (July 22, 1974)



(c) the Teshio River (Sept. 26, 1973)



(d) the Sarobetsu River (Sept. 26, 1973)

Fig. 7 A longitudinal distribution of the surface salinity.

constant value 0.013～0.015 Cl‰ from the front of the salt wedge to the river mouth and steeply increases to 6.0 Cl‰ at the region 0～−1.0 km. Because the thickness of the fresh water layer is large as 4.0 m and the interface is steady, salinity diffusion through the interface cannot influence the surface salinity. As shown in Fig. 7(c), the surface chlorinity of the Teshio River increases from the value of 0.01 Cl‰ at the front of the salt wedge (20 km upstream) to 1.7 Cl‰ near the mouth. The curve shows the typical distribution of surface salinity in an ordinary river. At the Sarobetsu River (Fig. 7(d)), the surface chlorinity 0.5 Cl‰ at 0 km is the same value as that of the Teshio River at the point 11. 5 km where the Sarobetsu River joins the Teshio River. The value of chlorinity reaches its maximum value 2.9 Cl‰ at the point 2.2 km upstream from the junction.

4 A change of the saline water intrusion

The salt wedge begins to recede, when the river discharge increases owing to rainfall. In order to observe the movement of the salt wedge according to the tide and the change of the river discharge, we set a salinity meter and a Step-type Interface Meter[6] at a station (Isoyabashi) 315 m upstream from the mouth of the Shiribetsu River. The topography of the river bed is almost flat in the cross section and the water depth is about 2.5 m at this station. A sensor of the salinity meter was settled at a point 20 cm above the bottom of the river about 3 m off the left bank. The Interface Meter was also set at almost the same place as the sensor. The change of salinity of the bottom water and the level of the interface whose chlorinity was set as 5.0 Cl‰ were continuously recorded by a six channel

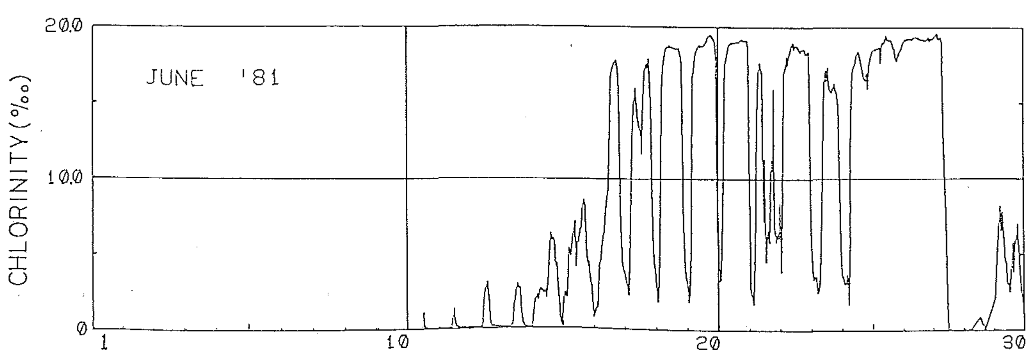


Fig. 8 A change of the bottom chlorinity observed at Isoyabashi, 350 m upstream from the mouth of the Shiribetsu River (June, 1981).

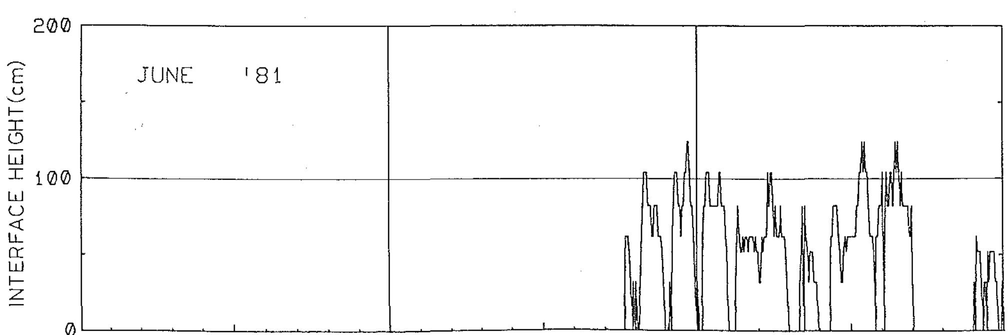


Fig. 9 A change of the internal level observed at Isoyabashi (June, 1981).

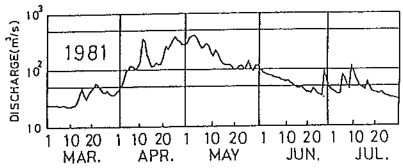


Fig. 10 A change of the river discharge of the Shiribetsu River (March ~July, 1981).

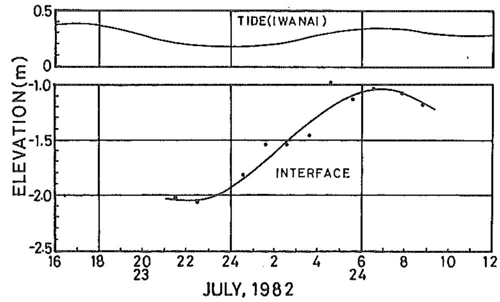


Fig. 12 The tide and the internal wave observed at the station, 810 m upstream from the mouth of the Shiribetsu River (July 23~24, 1982).

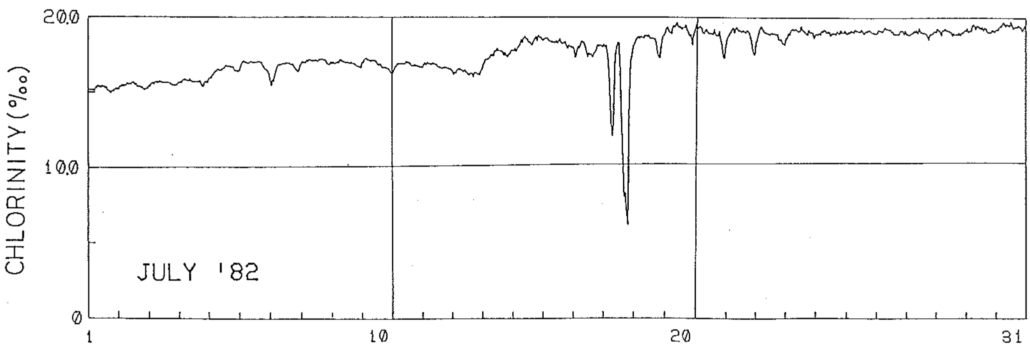


Fig. 11 A change of the bottom chlorinity observed at Isoyabashi (July, 1982).

recorder at the riverside during the period from June to October, 1981 and 1982.

From the records, the changes of the bottom chlorinity (taking the background as 0.02 Cl‰) and the interface height from the bottom observed in June, 1981 are shown in Figs. 8 and 9. The river discharge of the Shiribetsu River from March to July, 1981 was observed by the Hokkaido Development Bureau as shown in Fig. 10. According to the discharge curve, a large discharge was caused by the flood in snow melt season of April and May. When the discharge decreased to 45 m^3/s on July, the salt water of thin salinity (1.1 Cl‰) began to penetrate into the river mouth. The value of chlorinity reached 17.6 Cl‰ which is nearly the same value with the sea water, when the discharge decreased to 31 m^3/s on July 17. As seen in Figs. 8 and 9, the front of the salt water moves up and down-stream according to the tidal motion and the interface level fluctuates with the wave height about 1 m. The change of the river discharge also influences those movements in a long time scale. In the summer season without a heavy rainfall, the salt water can steadily remain in the estuary. As an example of this season, Fig. 11 shows the bottom chlorinity in July, 1982.

The interface level was measured every one hour for 11 hours from 23 to 24 in July, 1982, at the station 810 m upstream from the mouth of the Shiribetsu River. Figure 12 shows the relation between the tidal motion and the internal wave. The surface level at the station can be taken as the same with that recorded at Iwanai Harbour located about 21 km east from the mouth. From this figure, it can be seen that the amplitude of the internal wave is 6.3 times as large as the tidal motion and the phases of both wave motions are nearly the same.

5 Conclusion

Based on the observational results of the salt wedge and the surface salinity at estuaries of the Shiribetsu, Mogami and Teshio River, the longitudinal distribution of the surface salinity was studied in relation to the behavior of the salt wedge. The behavior of the salt wedge is largely influenced by the topography of the river bed, and a mixing of the fresh and salt water is extremely violent at the river mouth and also at the region where a big projection on the bed obstructs the flow.

The salinity distribution in the Teshio River shows a typical form in the common estuary. It steeply increases at the front of the salt wedge and then the gradient of salinity-distance curve is slow until the river mouth. On the other hand, the distribution has two steps in the Shiribetsu River influenced by the topography of the bed. When the thickness of the fresh water layer is large and the interface is steady, the salinity diffusion through the interface cannot influence the surface salinity along the salt wedge except near the mouth as seen at the Mogami River.

The changes of the bottom chlorinity and the interface level were observed using a salinity meter and a Step-type Interface Meter settled near the mouth of the Shiribetsu River. According to the observational results, the salt water with thin chlorinity began to penetrate into the mouth in the middle of June after the flood season. The chlorinity reached the value of the sea water after several days.

Under the influence of the tide, the front of the salt water repeated intrusion and receding, and the height of the internal wave motion reached over 1 m. The change of the river discharge also influenced those changes of a long time scale. The amplitude of the internal wave was 6.3 times as large as the tidal motion.

Acknowledgement

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