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INFLUENCE OF SHALLOWS ON SALT WEDGE INTRUSION IN TAKASE RIVER

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Abstract: Takase River is an effluent channel of a brackish-water lake named Lake Ogawara. It has mild slope and has vast shallow terrace in the middle reach of the river. Salt water intrusion to the lake is probably influenced by the existence of the shallow area. In this study, an extensive field measurement was carried out using 18 salinity meters, 68 thermometers and 3 current meters in order to investigate the flow characteristics in the shallow terrace and its influence upon the vertical structure in the channel. The measurement results showed that the flow retardation in the shallow area intensified the density stratification in the channel during the period of rising tide. This result is consistent with the salinity record obtained at a monitoring station near the lake.

Key words: Salt water intrusion, Field measurement, Salinity stratification

1. INTRODUCTION

Takase River is an effluent channel of a brackish-water lake named Lake Ogawara(Fig.1), which is located at the northeast end of Japan’s main island, within Aomori Prefecture. Salt wedge intrusion in the river and the salinity circulation in the lake have big influence on water quality and biological environment(Ishikawa 1991). Especially, the proper salinity concentration is important for the breeding of *Corbicula Japonica*(Tsuruta 2002), a tiny clam commonly used in Japanese miso soup. On the other hand, there is a request to dredge Takase River for the purpose of flood control. The change of topography will cause the change of flow pattern and scale of salt wedge intrusion. In order to manage the brackish-water environment properly, it is important to investigate the relationship between the topography and flow pattern of salt wedge intrusion.

Fig.2 shows the study area and the unique topography of Takase River. The width of river is quit big at midstream, but most of cross section is shallow terrace and the channel is narrow. Laboratory Experiments(Fujiwara, 1997) on the salinity intrusion suggested that the intensity and the frequency of the intrusion may be highly affected by this unique topography. Field measurements by Fujiwara(2000) at this area did not get satisfied data to show the flow pattern of salt water intrusion. In this study, with large number of salinity meters and temperature loggers, detail characteristics of salt water flow in the shallow terrace and its influences on salt wedge intrusion are investigated by a field experiment.

2. FIELD EXPERIMENT

The average water stage of Lake Ogawara is T.P.+40 cm, and average tide level at Takase river mouth is T.P.+10 cm. The surface slope is quite gentle, about 0.000045. During the full tide the tide level at river mouth, in most cases, are T.P.+40 cm to +70 cm. Salt water intrusion usually happens during this period of time.

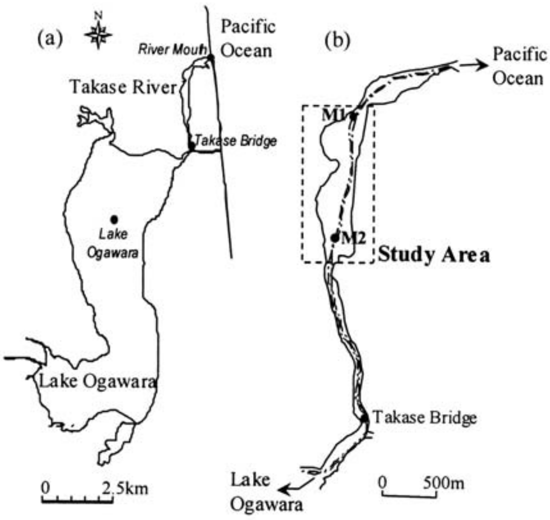

Fig. 1 Study area

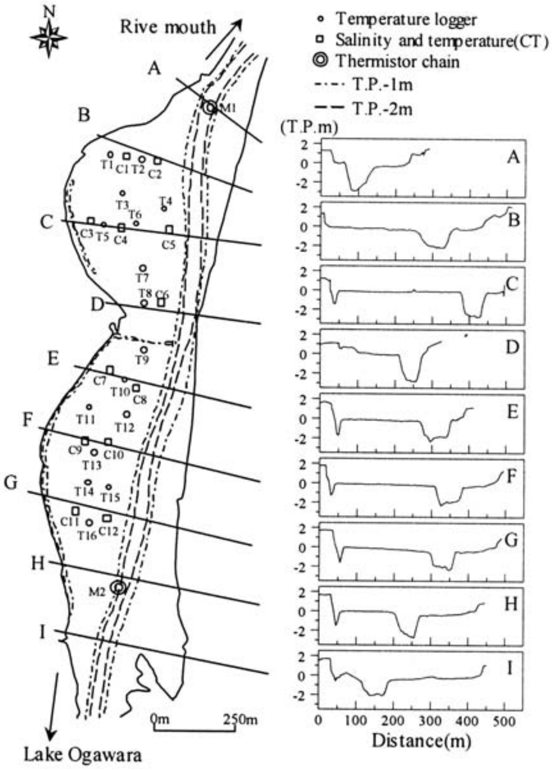

Fig. 2 Study area and measurement stations

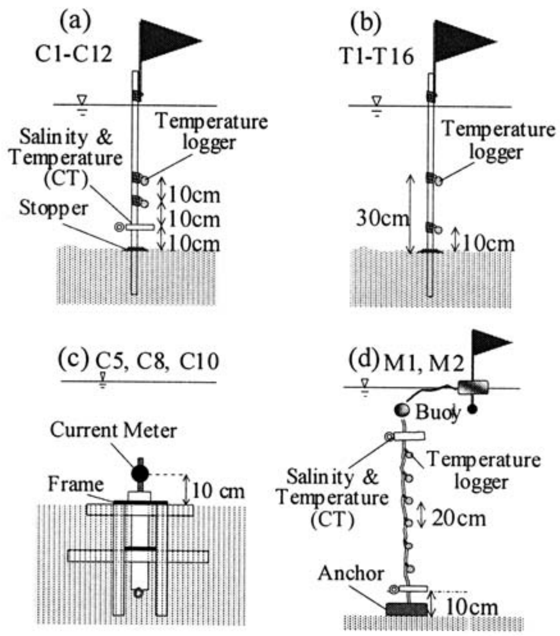

Fig. 3 Equipments

The experiment was conducted in a shallow area of 1.5 km long, as shown in Fig.2, for one week in August, 2002. The width of the shallows is 300-400 meters, and its ground level is almost constantly T.P.-10 cm. The channel is 60 meters wide and 2-3 m deep from the shallow terrace.

The measurements equipments are showed in Fig.3. Salinity was recorded with 18 salinity meters (Alec Electronics Co., Ltd, MDS-CT and Compact-CT). At C1-C12(Fig.2), they were fixed at 10 cm from riverbed. Temperature was recorded with 68 loggers (Onset, Hobo Water Temp Pro and StowAway TidbiT). They were fixed at points C1-C12 and T1-T16(Fig.2). Because the seawater is considerably cooler than the lake water in the season, it is possible to estimate the motion and the mixing of the waters from the records of thermometers which are much cheaper than salinity meter. Velocity was measured with 3 electromagnetic current meters (Alec Electronics Co., Ltd, Compact-EM) at C5, C8 and C10, 10 cm from riverbed. At water channel, salinity meter and thermistor chain were set up at stations M1 and M2 to measure profiles (Fig.3d). The salinity at upper layer and bottom layer and river flow rate are monitored at Takase Bridge(Fig.1) and the water stage is monitored at river mouth, Takase Bridge and center of the lake.

Salinity meters and temperature loggers were set to record data at 1 minute interval. Velocity meters were set to record data in 10 seconds at each minute with sampling interval of 1 second. The velocity data were obtained with the average in 10 seconds.

Water stage of the lake and tide level at river mouth, flow rate and salinity at Takase Bridge, solar radiation and rainfall at observation tower (center of the lake) during the week of field measurement are plotted in Fig.4. Aug. 7-10 are spring tide.

Salt water intrusion appears when tide level is higher than water stage of the lake in all seven days(Fig.4). Everyday, the salt wedge reaches Takase Bridge Station. Hereinafter, they are named event 1−7. Event 3 and event 4 are middle level intrusion. Because there were rainfall in the morning of August 7 and water stage in the lake increased 10 cm than usual, as a result, the scale of salt wedge intrusion appeared after event 5 were small, even it was the period of spring tide. During the week, the equipments fixed at 10 cm from riverbed were not exposed in air. It means all shallow terraces were covered in water during the week of measurement.

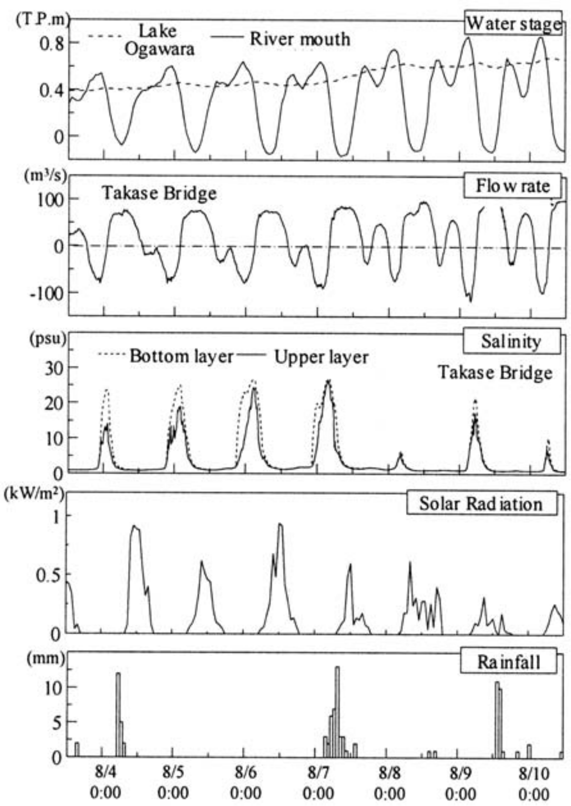

Fig. 4 Flow and meteo rological conditions Aug.3 12:00-Aug.10 12:00)

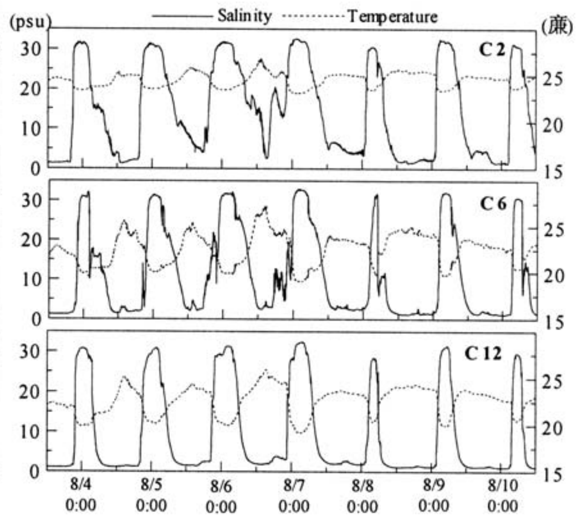

Fig. 5 Salinity and temperature

3. INTERRELATION BETWEEN SALINITY AND TEMPERATURE

Fig.5 shows time series of salinity and temperature at C2, C6 and C12. Everyday the maximum salinity concentration reaches 30 psu. The temperature decreases with the increase of salinity. The interrelation between salinity and temperature showed in Fig. 6. Different event has different curve, and different point has different curve even at same event. The reason for this could be considered as: (a) water depth is different at each point; (b) water temperature varies during the mixing process of intrusion; and (c) temperature of river water and solar radiation varies everyday.

In short time period the interrelation between salinity and temperature can be expressed by straight line. By regression analysis, the coefficients can be estimated by the least squares method. Salinity can be interpolated or extrapolated in the time and space with temperature data.

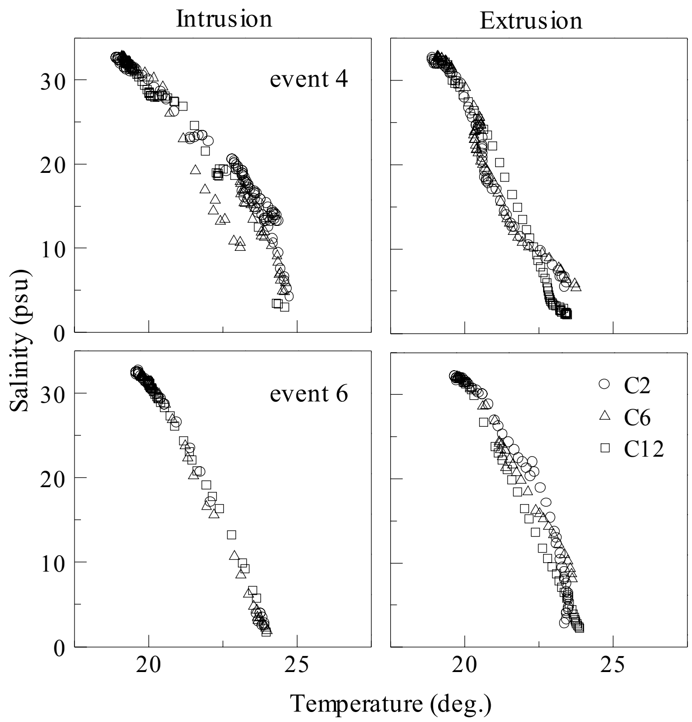

Fig. 6 Interrelation between salinity and temperature

4. RESULTS AND DISCUSSION

During the experiment, salt wedge intruded up in every tide, but the largest intrusion occurred on Aug. 7(event 4), the day of the first spring tide, after that the stage of lake water rose up due to an intense rainfall in the day.

4.1 FLOW PATTERN AT SHALLOW TERRACE

Fig.7(a)-(l) show the salinity distribution of event 4, which are the contour lines at 10 cm from river bed, plotted at each 5 psu. Velocity vectors are plotted, too.

The intrusion happens at 2:00 p.m., and 1 hour later salt water reaches M1 station. In Fig.7(a), the salt wedge intrudes to upstream along river channel but not expands to shallow terrace. The 5 psu contour line at shallow terrace A is remains of salinity from last event. In Fig.7(b) the salt wedge develops and arrives the station M2, and at same time salt water expands to shallow terrace A. Around 7:00 p.m., the tide level decreases to a low point(Fig.4), so intrusion stops. In Fig.7(c) and (d) the salt water extrudes from shallow terrace A, but the front of salt wedge advances along the channel a little.

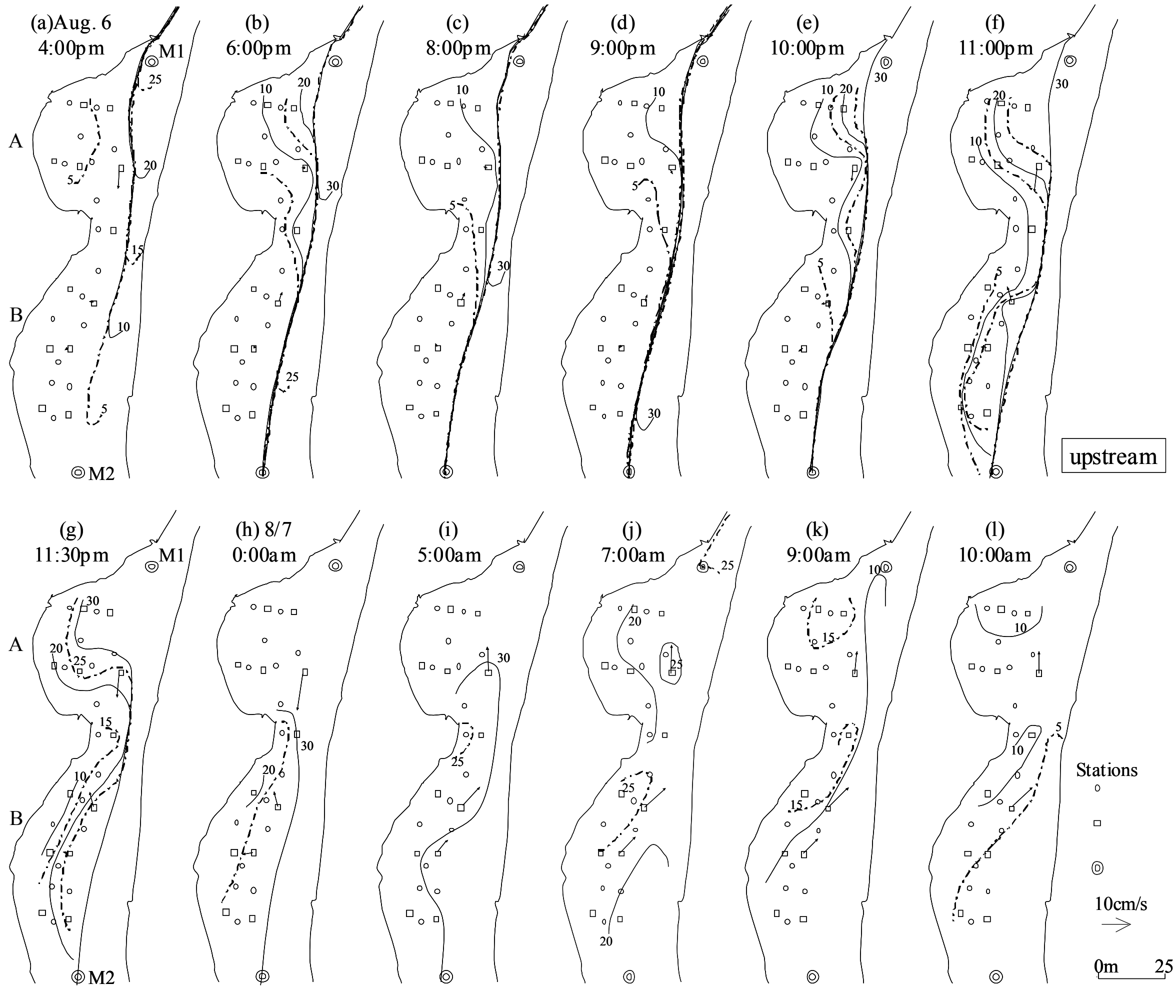

Fig. 7 Contuour line of salinity, event 4 (Aug.6 4:00-Aug. 7 10:00)

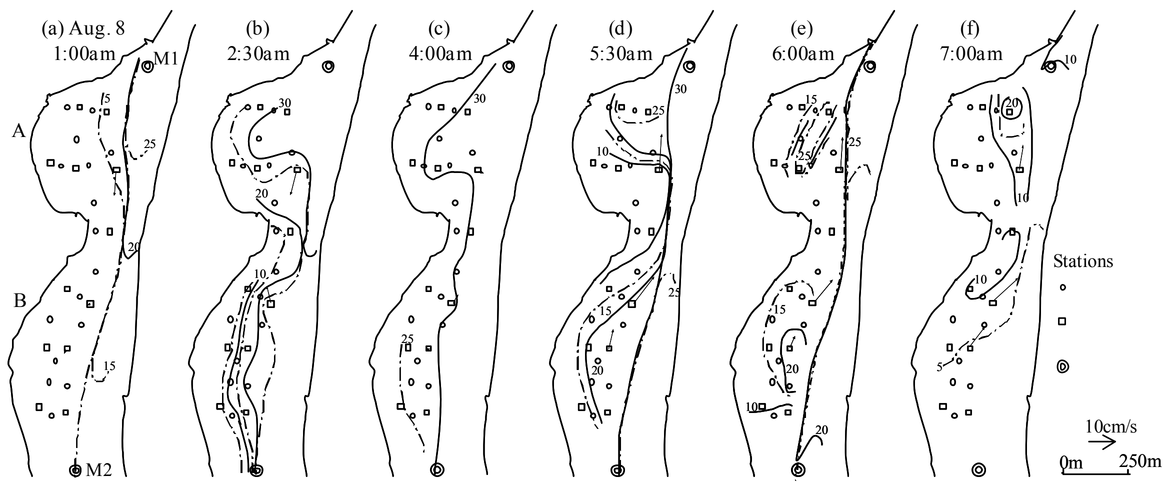

Fig. 8 Contour line of salinity, event 5 (Aug. 8 1:00-7:00am)

In Fig.7(e), the salt wedge intrusion starts again and expands to shallow terrace A. Half an hour later, salt water reaches shallow terrace B and expands to left bank of river slowly (Fig.7f and Fig.7g). Fig.7(h) shows salinity is over 30 psu at shallow terrace A. Around 1:00 a.m., shallow terrace, both A and B, are full of salt water.

At 4:00 a.m., current changes its direction as tide level decreases. In Fig.7(i), salt water extrudes from shallow terrace and channel. In Fig.7(j), (k) and (l) show that salt water at channel extrudes faster than what at shallow terrace. Some salt water remains at middle part of shallow terrace and moves to terrace A slowly, and keep higher salinity than surrounding water.

In Fig.8(a)-(f) salinity distribution of event 5 are plotted. Before this event, the water stage of Lake Ogawara has risen with rainfall, so salt water intrusion is not strong. Same with Fig.7, from Fig. 8(a), it could be noticed that salt water flows along the channel first. Then it expands to shallow terrace (Fig.8(b) and (c)). At the peak of intrusion, salinity at shallow terrace is over 25 psu. During the extrusion, salt water at channel moves out faster than that at shallow terrace (Fig. 8(d) and (e)) and high salinity remains at terrace A(Fig.8(f)). So, the flow pattern over sallow terrace is same even with weak intrusion of salt wedge.

4.2 THE INFLUENCE OF SHALLOW TERRACE

The stratification at channel can be discussed by salinity data from Sta. M1, Sta. M2 and Takase Bridge Station.

Fig.9 shows the records of event 4: (a) the water stage at the river mouth and the center of the lake; (b) the flow rate of Takase River(minus value means the flow from the ocean to the lake); (c)-(e) salinity of the upper and bottom layer at three stations, M1, M2 and Takase Bridge, respectively. Fig.9(b) shows two waves of backwater from the ocean corresponding to the high tides in the late afternoon of Aug. 6 and in the early morning of Aug. 7. Salinity of both the upper and the bottom layers at the most downstream station(M1) responds to the first high tide and keep at high level till the end of the second high tide. On the other hand, a difference of salinity can be observed between the upper and the bottom layers for a long time period at M2 station which is located at the upstream end of the shallows. At the Takase Bridge, the difference of salinity between the upper and the bottom layer is still observed, but its period is shorter than what at M2 station.

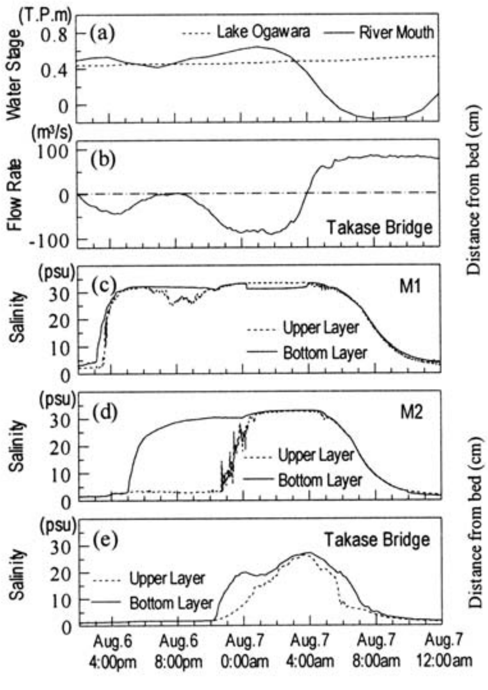

Fig. 9 Data series of event 4

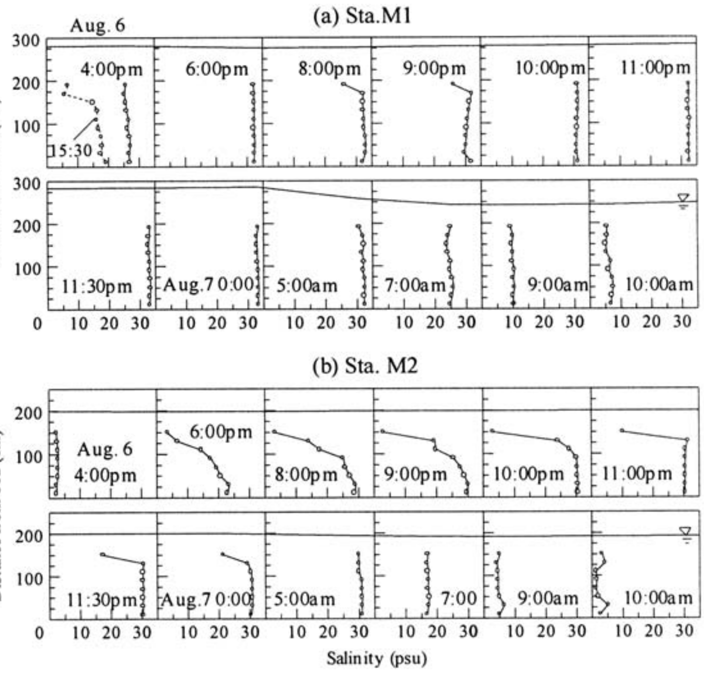

Fig. 10 Vertical profiles of salinity

The Fig. 10 shows the profile of salinity at station M1 and M2. The stratification at M1 and M2 showed in Fig.9 and Fig.10 can be explained with referring Fig.7. Because the water with low salinity extrudes out from terrace A to river mouth around 8:00 p.m. Aug. 6 (Fig.7(b)-(d)), salinity at upper layer of Sta. M1 decreases at same time. On the other hand, the salinity at upper layer of Sta.M2 keeps at low level in 5:00 p.m.-10:00 p.m.. The reason is that the salt water does not reach terrace B(Fig.7(b)-(e)), and water with low concentration of salinity is pushed out from terrace. In addition, an intense fluctuation of salinity is observed in the upper layer when it rises up (11:00 p.m.-0:00 a.m.). At same time period, the front of salt wedge is passing Sta.M2 (Fig.7(f) and (g)), so it could be considered that it is caused by the interaction between salt water in the channel and the low salinity water flowed out from the shallow terrace B. Around 2:00 a.m. the salinity at upper layer of Takase Bridge Station becomes same with bottom layer. It is about 1 hour lagged behind that of Sta. M2. At that time the flow rate at Takase Bridge is 0.7m/s and the distance between two stations is 2.5 km. So, it is considered that salinity at Sta.M2 becomes uniform first, then it flows to Takase Bridge and causes the uniform of salinity there.

From the long-term salinity records at the Takase Bridge, it has been noticed that the moderate mixing appears during the period of middle-scale intrusion and the well mixing corresponds with the large-scale intrusion during the period of spring tide. The mechanism can be inferred from above field experiment: During the period of middle-scale intrusion, the fresh water is pushed out from terrace to surface layer of the channel. The flow is retarded at terrace and lags behind the flow at the channel. So, the density stratification at the channel is intensified. On the other hand, during the period of spring tide, salt water replaces fresh water at shallow terrace during the first high tide. Then, it is easy to became fully mixed water at the second high tide. The latter is not confirmed by field experiment this time. More studies are needed to verify the above inference.

5. CONCLUDING REMARKS

In order to investigate flow characteristics in shallow terrace and its influence upon the vertical structure in the channel, in this paper an extensive field measurement was carried out by using 18 salinity meters, 68 thermometers and 3 current meters. The measurement results showed that the flow retardation in the shallow area intensified the density stratification in the channel in rising tide. This result is consistent with the salinity record obtained at a monitoring station near the lake.

In field data analyzing, salt wedge intrusion is usually related to the variation of tide level. Although the influence on salt wedge intrusion discussed in this paper is caused by the unique topography of the river, the phenomenon may appear not only in Takase River, but also in other rivers.

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