Characteristics of Salt Water Movement in Mouth of River Iwaki

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Abstract

The present study aims to investigate the characteristics of the motion of salt water and to show the temporal fluctuation of the vertical salinity distribution in Lake Jusan located in the estuary of Iwaki River in Aomori Prefecture, Japan. The Lake Jusan is the best productive water area of the shellfish, corbicula, in Japan in 2013. Then, the lake is very important in Aomori Prefecture as corbicula's home. However, the change of the brackish environment influences the corbicula shellfish's harvest, and the shellfish harvest changes every years. Now, it is important to make clear the characteristics of the motion of salt water in the lake. In the present study, observations for the motion of the salt water going up to the lake and going down from the lake to the sea were carried out from June to September in 2015. The time change of the salinity distribution in a perpendicular direction is investigated in the present study. The vertical distributions of the salinity are shown clearly by theory and observations. And the present study shows that the movement of the saltwater in the lake can be generated well by the theory given by Sasaki, Tanaka and Umeda (2011).

1. Introduction

The Iwaki River in Aomori Prefecture, Japan, flows through the Tsugaru Plains into Lake Jusan, and goes through the lake mouth into the Japan Sea (Figure 1). Iwaki River is a class 1 river managed by the Ministry

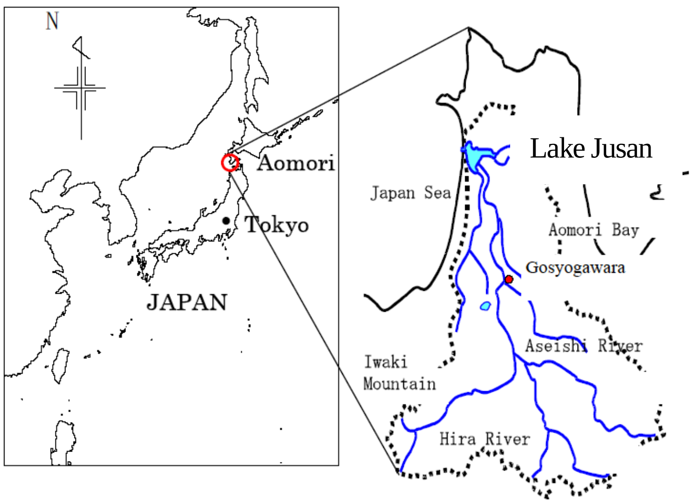

Figure1. Lake Jusan and Iwaki River

of Land, Infrastructure and Transport. The mouth of the Iwaki River, which becomes the mouth of the Lake Jusan, is locally referred to as Mitoguchi. Namely, the lake mouth is called Mitoguchi in local. In the past, there were many engineering works at the river mouth to make a new river channel from the lake to the sea. However, all those river channels newly developed were destroyed by high waves during rough seas caused by strong westerly winds in winter (Sasaki and Takeuchi (2003)). The lake overflowed, and the blockage of the water channel caused an extensive flood in the lower river basin. These floods caused considerable damage in the lower river basin of the Iwaki River and in all areas adjacent to Lake Jusan. There were two kinds of floods in Iwaki River. They were the floods due to the increased rainfall, and the floods due to the blockage of the water channel. Local inhabitants therefore petitioned the national government to implement flood control measures in the Iwaki River. The government established a construction office at Goshogawara town in the river basin, and the flood control measures by the nation were initiated in December 1918. When eight-year observations in the estuary for the geographical characteristics, and waves, and water currents had been completed, the construction of the Mitoguchi jetty to prevent the blockage of the river mouth was started as a pier from land to sea in 1926. While initial efforts were focused on the construction of a pier on the northern side of the river mouth, in 1928 it was decided to construct jetties instead given the effectiveness of the pier as a jetty. Construction was initiated on the south jetty in 1930, and the entire Mitoguchi jetty construction project was completed 16 years later in 1946.

Figure 2: Observation Station ▼ in 2015.

As a result, the river project provided environments of safe sailing of boat in the river channel, and of preventing blockage of the river mouth and of seawater entering the lake as shown by Sasaki et al (2003). However, given the marked impact these changes have had on the water quality of the estuary system, we observed saltwater movement in the river mouth in this study. Lake Jusan is important lake in Aomori Prefecture as corbicula's production area. Because the corbicula grows up in the brackish lake, the motion of salt water to the lake causes the important effect for the growth of the corbicula.

Sasaki, Asari and et al (2009) and Sasaki, Tanaka and Umeda (2010) have already shown the movement of saltwater in the Lake Jusan and investigated horizontal distribution of the saltwater moving in the lake. They showed that the seawater goes up to the south lake through the lake center and reaches the south shore of the lake and that the seawater moves to the interior east of the lake through the shallow area near the east of the lake, and reaches the east end of the lake. And they also showed that the mixing of the freshwater into the seawater occurs considerably in the lake. Then, the time change of the salinity distribution in the perpendicular direction is investigated with the field observations in the study. Sasaki, Tanaka and Umeda (2012) showed the theory on the stratified flows of salt water in middle of the lake, and Sasaki, Tanaka and Umeda (2015) showed that their theory can generate well the stratified flows of salt water in the lake.

In the present study, the characteristics of the stratified flows of the salt water are investigated. Field observations for the movement of the salt water going up to the Lake Jusan and going down from the Lake Jusan to the sea were carried out from June to September in 2015. In the observations, water temperature, the flow direction, the flow velocity, and the salinity are measured. To supplement the field observation limited timewise and spatially, the saltwater movement was investigated theoretically by theory given by Sasaki、Tanaka and Umeda (2012).

2. Field observations for salt water movement

Field observations for the motion of the salt water going up to the Lake Jusan and going down from the Lake Jusan to the sea were carried out daring from June to September in 2015. In the observations, water temperature, electric conductivity, the flow direction, the flow velocity, and the density of salinity were measured. The measurement of the water qualities was made at a station shown

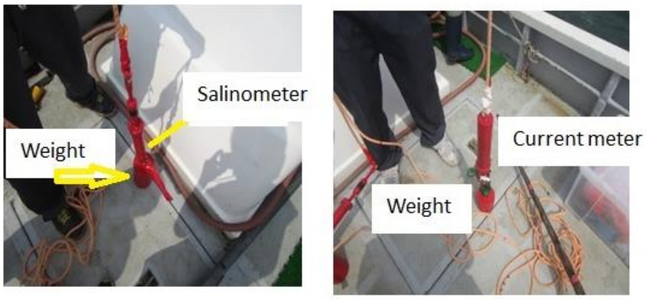

Figure 3: Salinometer and Current meter

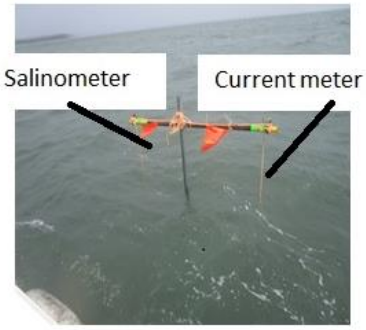

Figure 4: Observations for Salinity and flow velocity during from 14 July to 14 September in 2015. The water depth is about 130cm.

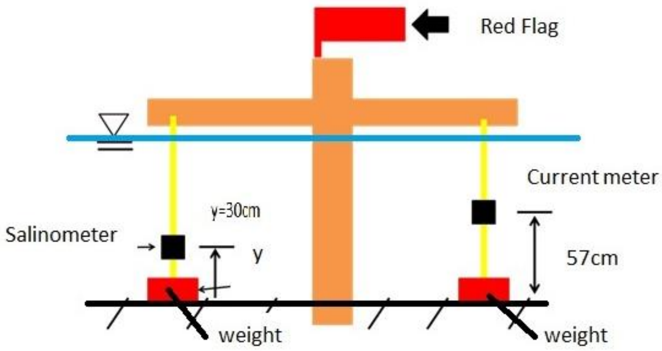

Figure 5: Current meter was set up at the 57cm height from the lake bottom. Salinometer was taken at the 30cm height from 14 July to 31 July, and after that, it was taken at 60cm height for 2 weeks from 1 August, and next, at the 90cm height for 2 weeks from 16 August, and the last, at the 120cm height for 2 weeks from 1 September. In this station, the water depth is about 130cm.

in Figure 2. The observation point was installed in the middle of the lake (Sasaki, Tanaka and Umeda (2015)), however, the observation point of 2015 is near the lake mouth than the observation point of 2014. Figure 3 shows the salinometer and current meter used in the field observation. And Figure 4 shows the meters set up at the observation station shown in Figure 2. As shown in Figure 5, current meter was installed at the 57cm height from the lake bottom. The salinometer was set up at the positions of four height in 2015. Those heights were 30, 60, 90 and 120cm from the lake bottom respectively. The height 30cm was during from 14th July from 31st July, and the 60cm height was taken during from 1st August to 15th August, and the 90cm height was taken during from 16th August to 31st August, and the last, the height 120cm was taken during from 1st September to 14th September.

3. Characteristics of Flow in Jusan Lake

The water level in Jusan Lake and the river discharge entered to the Jusan Lake have been observed by the local office of the Ministry of Land, Infrastructure and Transport. We can get the data on the water level and river discharge. Then, the velocity in the lake mouth can be calculated from the observation data given by the Japanese government local office. In the calculation, the mass continuity is used as shown Equation (1).

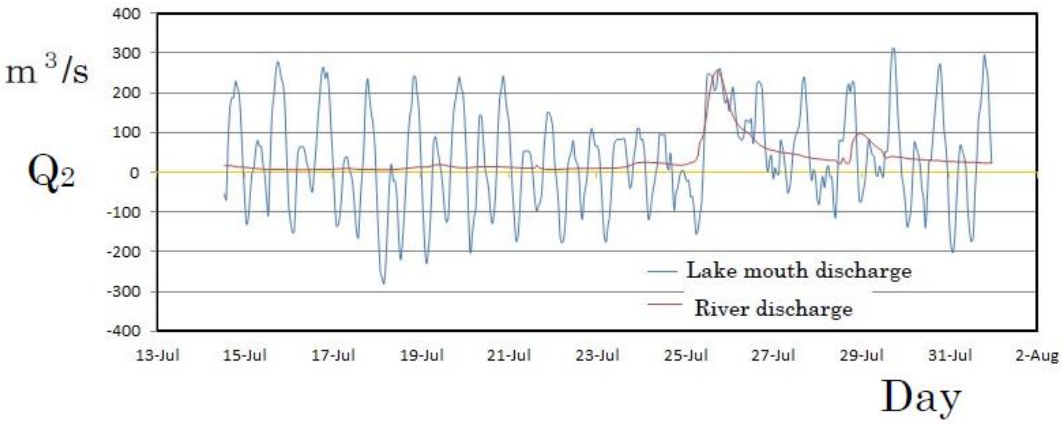

Figure 6: Discharge in the mouth of Lake Jusan. The discharge Q_2 becomes positive as water goes down from the lake to the sea, and negative during the backflow.

Namely, the Lake Jusan is located in the river mouth, then, the equation of continuity can be shown as follows.

$$Q_1 - Q_2 = A_l \frac{\partial \eta}{\partial t} \qquad \therefore Q_2 = -A_l \frac{\partial \eta}{\partial t} + Q_1 \qquad [1]$$

Where, Q_1 is the river discharge that enters from the river to the lake, Q_2 is the flow discharge in the entrance from the lake to the sea, A_l is the area of the lake, η is the water level of the lake, and t is time. In the equation (1), the discharge Q_2 becomes positive as water goes down from the lake to the sea, and negative during the backflow. When the discharge Q_2 becomes negative, the sea water went up to the lake before the flow direction changes. However, the time of the stratified flows near the bottom in the lake mouth is short, then basically, the positive value of the discharge Q_2 means the discharge of the fresh water from the lake to the sea, and the negative value of Q_2 means the discharge of the salt water entering from the sea to the lake.

Figure 6 shows the discharge in the lake mouth from 14 July to 1 August in 2015. As shown in the figure, the discharge Q_2 changes every day except during for few days from 25 July. The changing is due to

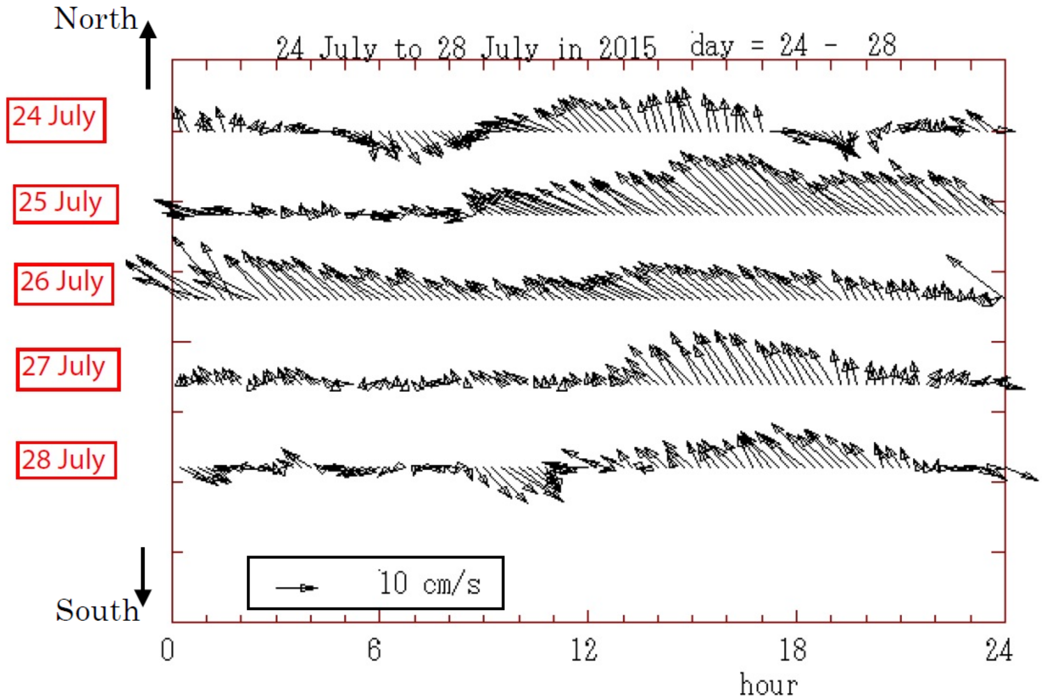

Figure 7: An example of current observations in Lake Jusan from 24 July to 28 July in 2015.

the tide. The fluctuation of the discharge is caused by the vertical motion of the sea water level induced by the tide. The water levels of the river and the sea influence the lake water level. The water level of the river rises only when it rains and the river water increases, however, the water level of the sea rises and descends every day. The water level of the lake becomes lower than the sea water level when the lake water level is rising after descending. At that time, the backflow is caused in the mouth of the Lake Jusan, and the sea water goes up to the lake. As mentioned above, the negative value of Q_2 means the backflow from the sea to the lake. Then, the backflow is caused every day if the river discharge is a little. There is no backflow on 26 July. This is due to the rainfall. Because the river discharge increases as shown in Figure 6, the lake water level rises.

Figure 7 shows an example the results of field observations for the velocity and the direction of the current at the observation station near the lake mouth in the middle of the lake as shown in Figure 2. The measurement of the velocity was made at the 57cm height over the lake bottom as shown in Figure 5. In Figure 7, the northward velocity is showing the movement of the lake water going down to the sea from the lake, and the southward velocity is showing the backflow from the sea into the lake. As shown in Figure 7, there are some backflows around 6 and about 18 in the morning and the evening on 24 July, and about 10 in the morning on 28 July, however, there are seaward flows all day on 26 July. The seaward flows is due to the small flood caused by the rainfall in the Iwaki River basin. Comparing between Figure 6 and 7, flows in the lake are following to the flows in the lake mouth. Then, we can conclude that the velocity in the lake is made and controlled by flows in the lake mouth.

4. Saltwater movement in Jusan Lake

The saltwater movement in the lake is shown by the change of the salinity of the lake water. Sasaki, Tanaka and Umeda (2012) showed theoretically as follows. Now, the mass per unit volume of the diffusion material is written by c. Then, the salinity is given by the diffusion material c. The diffusion material c is shown by the diffusion equation of Fick. On the seawater movement in the mouth of a river, we assume that the phenomenon is the same in the direction of the crossing. Then, the phenomenon of the seawater movement is shown by the next expression, Eq. (2).

$$\frac{\partial c}{\partial t} + u\frac{\partial (c)}{\partial x} = \frac{\partial}{\partial x}\left(D_x \frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial z}\left(D_z \frac{\partial c}{\partial z}\right) \qquad [2]$$

Where, t is time, x is horizontal coordinate in direction of main flow, z is vertical coordinate, Dx, and Dz are turbulent diffusion coefficients and u is velocity component of the flow in x directions. The coordinate x is taken from the river to the sea. The field of diffusion is divided into some layers along the depth for easiness now. The change in a perpendicular direction is assumed to be omissible small compared with the change of horizontal direction in each layer. Therefore, the equation (2) can be written as the next equation (3) in the k-th water layer.

$$\frac{\partial c_k}{\partial t} + u_k\frac{\partial (c_k)}{\partial x} = \frac{\partial}{\partial x}\left(D_{xk} \frac{\partial c_k}{\partial x}\right) + q_k \qquad [3]$$

where,

$$q_k = f_{zk}|u_k|\frac{\partial c_k}{\partial x} \qquad [4]$$

$$D_{xk} = l_{xk}|u_k| \qquad [5]$$

In the equations (3), (4) and (5), q is an amount of the material movement by the mixture between layers. In the equation (4), f_z is a coefficient for the mixture between layers and l_x is the mixing length. By taking some assumptions, Sasaki, Tanaka and Umeda (2012) showed the theoretical solutions (6) and (8) of Equations (3).

$$c_k = (C_{3k} - C_{1k})\{1 - \exp(-\alpha_{1k}\xi_k)\} + C_{1k} \qquad [6]$$

$u<0$

$$\xi_k = 0 \qquad if \quad \xi_k < 0 \qquad [7]$$

$$c_k = (C_{pk} - C_{1k})\exp\{-\alpha_{2k}(\xi_k - \xi_{ok})\} + C_{1k} \qquad [8]$$

u>0

where,

$$c_k = C_{p\,k} \qquad at \quad \xi_{ok} = \xi_k(t=0) \qquad [9]$$

$$\xi_k = \beta_{1k}\int |u_k| dt / l_o + \beta_{2k} x_k / l_o + X_{o1k} / l_o \qquad [10]$$

Where ξ_k is a new variable defined as the equations (10), β_{1k} 1 and β_{2k} are arbitrary constants that keep the type of the differential equation, X_{o1} is the position of the seawater front when t=0, and l_o is a typical length of the field. In the equations (6) and (8), α_{1k} and α_{2k} are constants which are always positively. The solution given as Eq. (6) is for the backflow. And the solution obtained as Eq. (8) is for seaward flow. In Equations (6) and (8), time becomes 0 at the commutation of the flow, and it starts respectively when the backflow and seaward flow begins, and constants C_{1k} and C_{3k} are the minimum value of the salinity and the maximum value of the salinity at any point x in the k-th water layer.

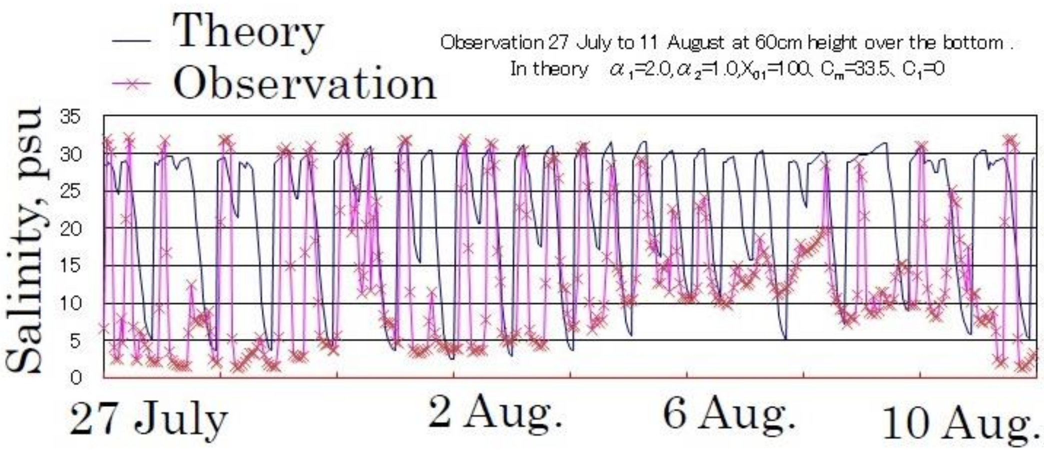

Figure 8. Comparison between the theory given by solutions (6) and (8) and the observations shown by red line with X for salinity at a depth 60 cm from the lake bottom on 27 July - 11 August, 2015. In the calculation, the constants α_1=2.5, α_2=1.3, X_{01}=100、C_m=33.5 and C_1=0 are used.

Figure 8 shows an example of the comparisons between theory and observation for 2 weeks from 14 July, 2015 in Lake Jusan. The theory given by Sasaki, Tanaka and Umeda (2012) is shown by a black solid line in the figure. The calculation of the salinity is made at the 60cm depth over the bottom near the center of the lake. In the theory, usually, the constant α_1 seems to be the range from 1 to 3, and the constant α_2 seems to be around 1. Those two constants are the important parameters that have relation with the saltwater movement. If they are not appropriate values, the theory is not suitable for the observations. As shown in the figure, the theory and the observations show a good agreement except on 7 August. A little disagreement has the cause in giving uncertain flow velocity obtained from Eq. (1). Then, it can be understood that the theory generates well the salt water going up, and strength of salinity and the continuance time of going up. The comparison between the theory shown by Sasaki et al (2012) and the observations also shows a good agreement for salinity at the height of 60, 90 and 120cm over the lake bottom, although showing was omitted. As shown in the Figure 8, the salinity concentration in the lower water layer near the lake bottom reaches to the magnitude of the seawater. According the observations, after the seawater is going up to the lake, water in upper layer becomes thin saltwater near the freshwater due to the mixing between the freshwater and the seawater. It suggests that the salinity is changing between the freshwater and seawater within several days.

4. Conclusions

In the present study, the characteristics of the motion of salt water and the temporal fluctuation of salinity in Lake Jusan are investigated with the field observations made at the central of the lake from 14 July to August in 2015 and the theory given by Sasaki, Tanaka and Umeda (2012). The present study shows as follows.
The comparison between the theory of Sasaki, Tanaka and Umeda and the filed observations shows a good agreement. In the theory, if the constants α_1, α_2, and X_{01} are taken appropriate values, the theoretical solution given by Sasaki, Tanaka and Umeda (2012) can generate well the movement of seawater going up and down in Lake Jusan. The salinity concentration in the lower water layer near the lake bottom reaches to the magnitude of the seawater.

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