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DISPERSION PATTERNS OF RIVER WATER IN LAKE BIWA

By

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Abstract

An observation of river water dispersion was carried out in Lake BIWA a few times in 1972. We observed the temperature and electric conductivity as tracers of the river water.

The dispersion patterns could be classified in the following three cases.

Case 1: The river water flows into the lake and disperses in the upper layer of the lake water.

Case 2: The river water flows parallel to the coast with the longshore currents made by the wind and breaking of the incident waves.

Case 3: The river water sinks at the river mouth and disperses along the lake bottom.

1. Introduction

The dispersion of river water into the lake is not similar to that of in the sea because, i) the river water is not always lighter than the lake water, ii) tidal currents do not exist, iii) the inertial momentum of the river water which flows into the lake is

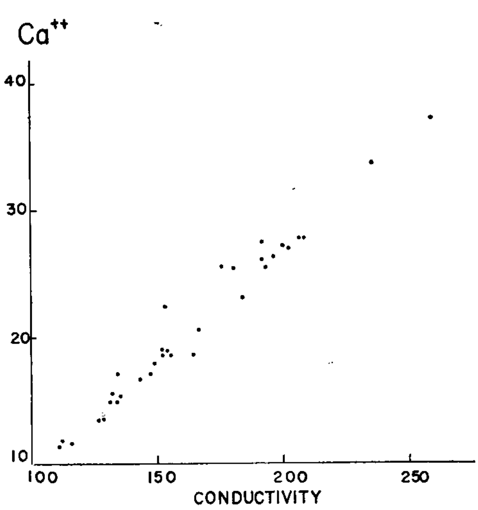

Fig. 1-1 Relations between Ca^{++} (mg/l) and conductivity ($\mu\mho$/cm) of water in the observed region on Aug. 20.

almost ineffective to the dispersion. Since it is very difficult to treat these phenomena quantitatively, we confined our interests in the present report to qualitative discriptions such as what phenomena and physical elements are effective to the dispersion. We are especially interested in the roles of advective effects.

We must be able to distinguish the river water and the lake water in order to know the dispersion. We selected the estuary of the Amano River as the field to be observed because the water of this river contains more calcium ions than the lake water. Fig. 1-1 shows the relation of conductivity and Ca^{++} based on the data used in **section 2.** It might be reasonable to estimate the mixing ratio of both waters from the value of the conductivity instead of Ca^{++} itself.

2. Case 1: *Dispersion in the upper layer*

Such a dispersion pattern was observed on June 26 is similar to that of the river water which flows into the sea. Standing at a macroscopic view point, the surface temperature of the lake water was high near the coast and became lower offshore (Fig. 2-1).

The temperature of the river water was about 22 °C and equals nearly that of the lake water near the river mouth. So it is difficult to know the dispersion by temperature distribution only. The lake water was stratified to a depth of 1 m. The temperature below the thermocline was almost uniform and was about 20 °C. Therefore the

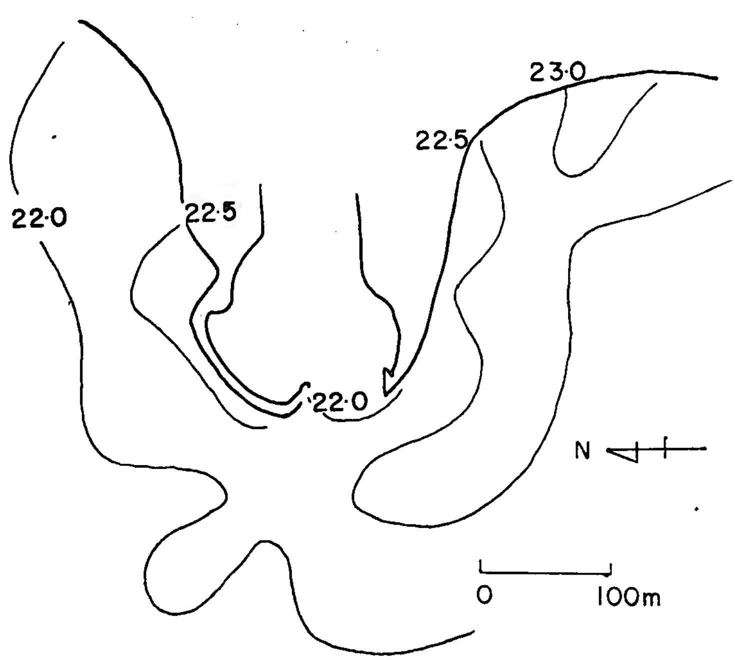

Fig. 2-1 Distribution of water temperature (°C) at the surface on June 26.

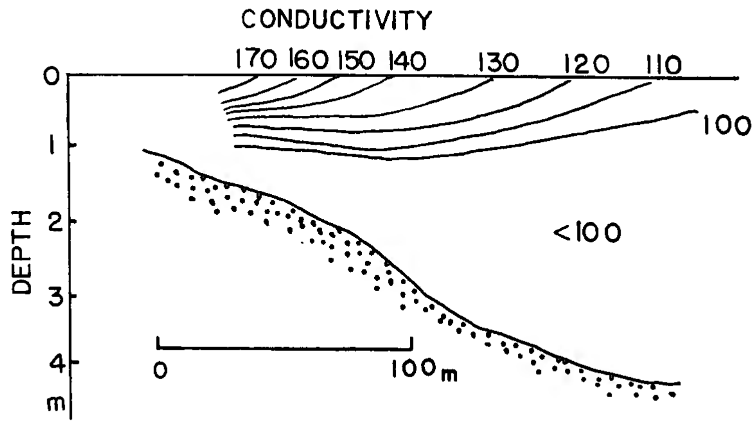

Fig. 2-2 Vertical distribution of conductivity ($\mu\mho$/cm) along the axis A-B shown in Fig. 2-3.

temperature of the river water was comparable to that of the upper water of the lake but about 2 °C higher than the lower water.

Fig. 2-2 shows the vertical distribution of the conductivity along the main axis of the flow. The conductivity of the lower water was almost constant and about 90 $\mu\mho$/cm. On the other hand that of the upper water decreased gradually offshore. It is clear that the river water was confined to the upper layer of 1 m thickness. Therefore, it may be considered that the river water could not be mixed toward the lower layer but the lower water could be mixed upward. The mixing of the both waters is an unidirectional process, i.e. somewhat analogous to entrainment.

As mentioned before, the dispersion should be influenced by the temperature distribution which is higher near the coast and lower offshore. Such a temperature distribution may be better balanced to the viscosity rather than to the Coriolis' force. If it were true, we can regard the flow as a density current. It may be considered that Fig. 2-1 shows such a density current. The main axis of the river water dispersion curves somewhat northward as is shown in Fig. 2-3. It may be explained that it is associated with the northwestward flow which is thought to be a density current formed by the temperature distribution.

Fig. 2-4 shows the distribution of the conductivity across the stream at a depth 0 m, 0.5 m, 1.0 m and 1.5 m respectively. The conductivity decreases downward on the left hand side of the flow upstream but has maximum value at a depth 1.0 m on the right hand side. It may be associated with the northwestward density current.

In the present case, as the momentum of river water flowed into the lake was not large, the strong mixing due to the vertical circulation might not be dominant. Fig. 2-5 shows the conductivity at the surface of the lake along the main axis of the dispersion. It decreases gradually downstream. It may be associated with a vertical mixing analogous to entrainment. We may consider the entrainment about an one-dimensional two layer flow. The equation of continuity is

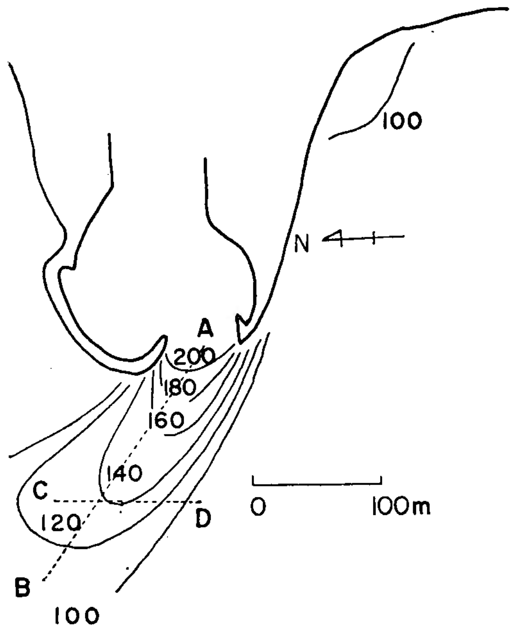

Fig. 2-3 Distribution of conductivity (μ℧/cm) at the surface on June 26.

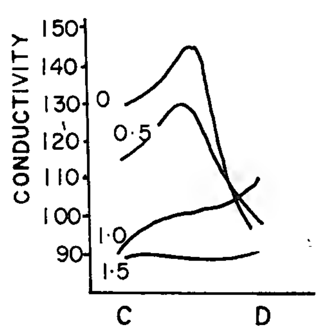

Fig. 2-4 Distribution of conductivity (μ℧/cm) along the axis C-D shown in Fig. 2-3 at depths of 0 m, 0.5 m, 1.0 m and 1.5 m on June 26.

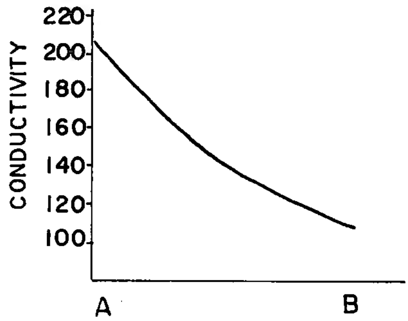

Fig. 2-5 Conductivity (μ℧/cm) at the surface along the axis A-B shown in Fig. 2-3 on June 26.

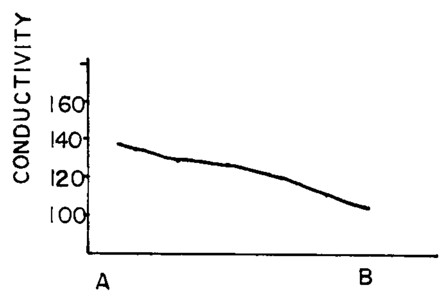

Fig. 2-6 Vertically averaged conductivity (μ℧/cm) along the axis A-B shown in Fig. 2-3 on June 26.

$$\frac{dU_1H_1}{dx}=CU_1.$$

The conservation of the conductivity is expressed as

$$\frac{dU_1H_1S_1}{dx}=CU_1S_2.$$

x: coordinate positive toward offshore.
U_1: the velocity of upper layer water.
H_1: the thickness of upper layer.
S_1: the conductivity of upper layer water.
S_2: the conductivity of lower layer water.
C: the entrainment coefficient.

S_1 is written in the conditions that S_2 and H_1 are constant.

$$S_1=(S_R-S_2)\exp\left(-\frac{C}{H_1}x\right)+S_2.$$

S_R: the conductivity of river water.

Thus S_1 decreased exponentially offshore. It seems that this result corresponds qualitatively to the decrease of conductivity shown in Fig. 2-5. But we should take a vertically averaged value of S_1 to compare with above result. The averaged value does, however, not decrease exponentially but linearly as is shown in Fig. 2-6. It may be due to the change of the width of the flow, more precisely due to the change of the area of the cross section of the flow, which may be concerned with lateral diffusion.

3. Case 2: *Dispersion along the coast*

As is shown in Fig. 3-1 and Fig. 3-2, we can easily understand the dispersion pattern of river water of this case. This dispersion pattern was observed on Aug. 20

when the wind speed was 7–8 m/s and its direction was toward the river mouth (NW-W). Such a dispersion should be influenced greatly by the wind. The temperatures of the river water and the lake water were 25 °C–26 °C and about 29 °C respectively, and the river discharge was 0.67 ton/sec. It is characteristic of this case that the wind-

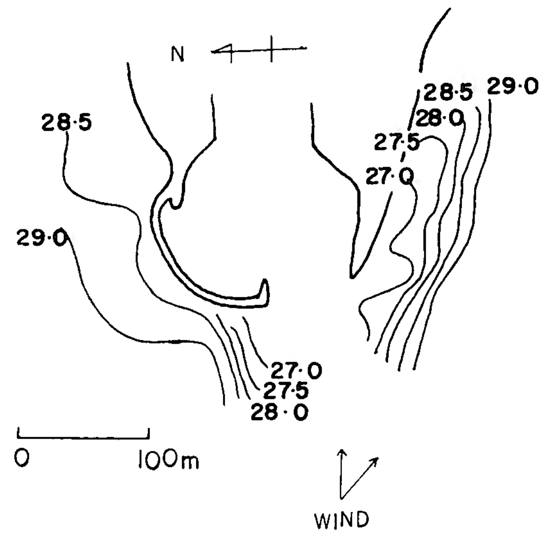

Fig. 3-1 Water temperature (°C) at the surface on Aug. 20. It is elongated three times offshore in order to express the meander of the contours.

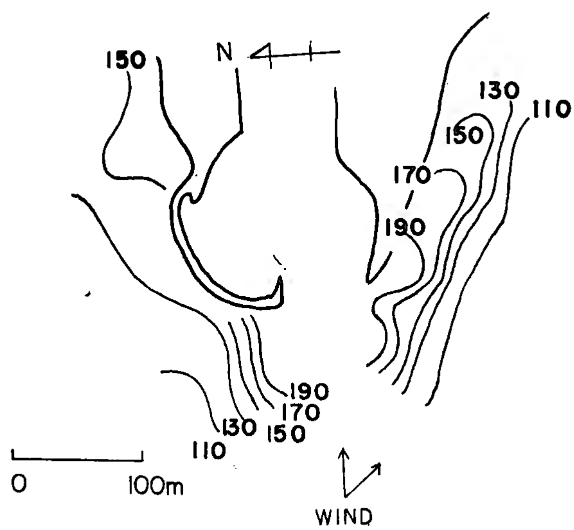

Fig. 3-2 Conductivity ($\mu\mho$/cm) at the surface on Aug. 20. It is elongated three times offshore in order to express the meander of the contours.

driven current and the longshore flow made by the breaking of incident waves play important roles in the dispersion. The longshore currents were studied by Bowen (1969) theoretically using the concepts of radiation stress discussed by Longuet-Higgins and Stewart (1964).

The river water and the lake water were mixed well vertically in spite of the temperature difference about 3 °C–4 °C. As the river discharge was very little, the momentum of river water flowing into the lake might be insignificant to the dispersion. Therefore the longshore flow might be dominated regarding the adventive process of the dispersion. The ratio of river water contained in the lake water along the coast is shown in Fig. 3-3. The ratio is small along the northern coast of the river mouth. Most of the river water seemed to be flowing along the southern coast. The ratio along the northern coast is almost uniform offshore but it decreases rapidly offshore along the southern coast. It might be considered that the river water was trapped to the coast.

The ratio of river water to the total volume of the coastal water within 20 m from the coast is shown in Fig. 3-4. It is clear that the ratio decreases downstream but not uniformly. If we consider the decrease of the ratio due to the diffusion perpendicular to the coast, the diffusion might not be uniform along the coast.

The mixing or exchange between the coastal water and outside water might not progress uniformly along the coast. When it may be considered that such a phenomenon is due to an advective process, we may remain only advective terms of the equation

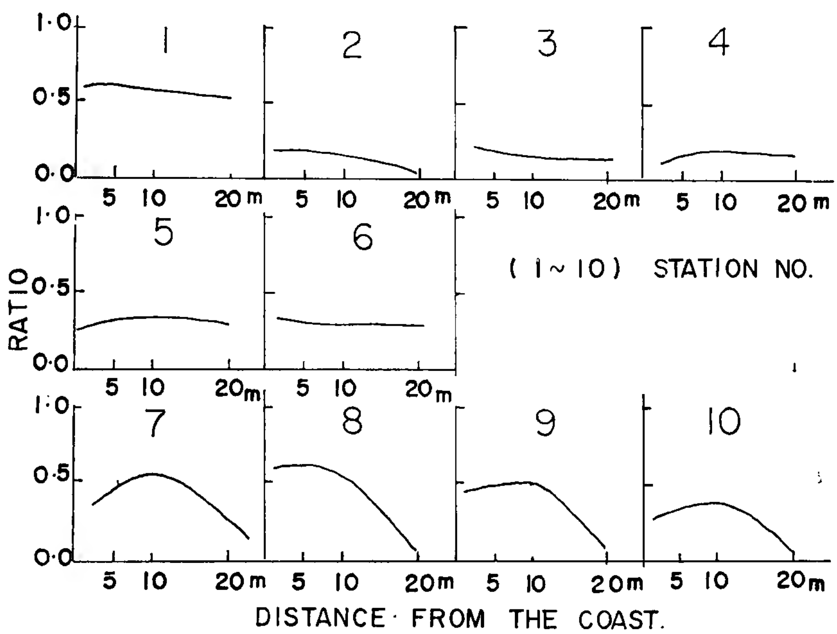

Fig. 3-3 Distribution of the ratio (nondimension) of the river water to the lake water at some stations toward offshore shown in Fig. 3-4 on Aug. 20.

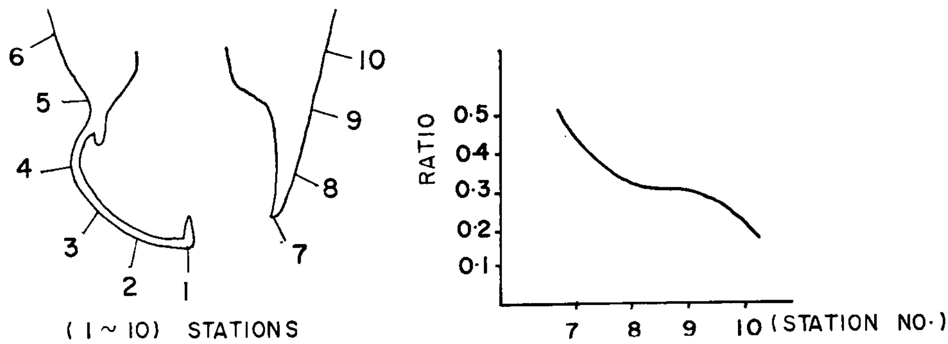

Fig. 3-4 Distribution of the ratio of the river water to the total volume of the coastal water along the coast within 20 m from the coast on Aug. 20.

of diffusion. The equation can be written as

$$u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}=0.$$

S: the ratio of river water at any points.

The above equation shows that the current direction and the gradient of S must be perpendicular to each other. Therefore the stream line must be parallel to the contours in Fig. 3-1 or Fig. 3-2. It means the meander of the longshore flow. Meandering currents were studied by Sonu (1972). He explained these meandering currents are a combined effect of circulation cells and parallel longshore flows.

In the present case, the effects of diffusion are not understood clearly, but it may be reasonable at an initial step to neglect the diffusion perpendicular to the coast because of the sharp gradient of the temperature and conductivity offshore. In such a condition we should recognize the dispersion as some advective effects and it may be reasonable that the dispersion in the present case is caused mainly by the meandering current near the coast.

4. **Case 3:** *Dispersion along the bottom*

Such a dispersion pattern was observed on Aug. 19. The river discharge was same as in the case 2. The water temperatures of the river and the lake were 25.5 °C-26.0 °C and about 29 °C respectively. The wind was weak and it was insignificant to the flow in the region. Through the observed area, the lake water was not stratified. In such a circumstance, we can know the dispersion of river water by observing the temperature distribution. We could find no fraction of river water in the upper water of the lake. But considering the density difference (temperature difference) between both waters, it can easily be understood that the river water which was denser had sunk at the river mouth. As is shown in Fig. 4-1 the influences of the river water on the temperature and conductivity are restricted near the bottom. The thickness of the bottom

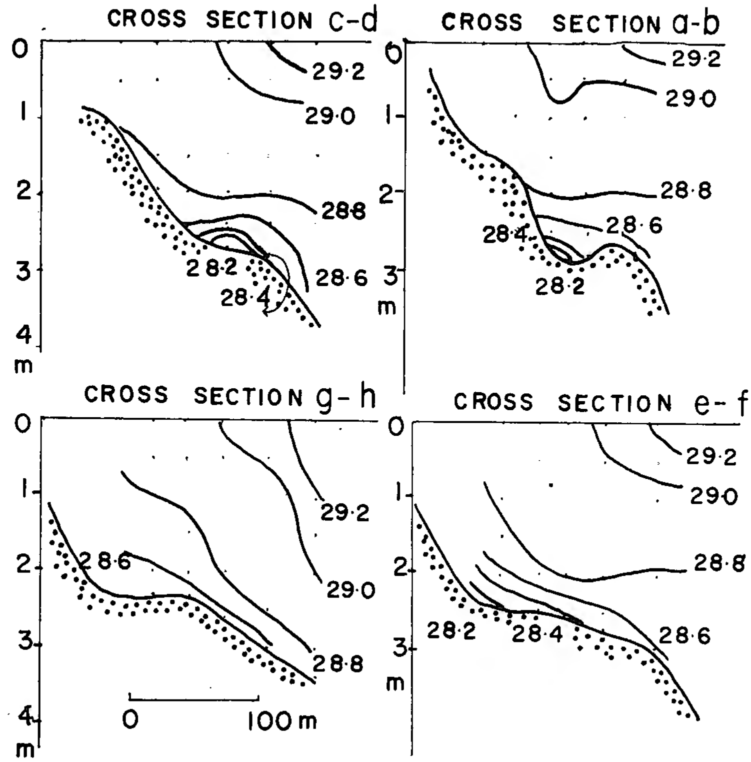

Fig. 4-1 Distribution of water temperature (°C) at some cross sections shown in Fig. 4-3 on Aug. 19.

layer containing a great amount of river water was restricted within 80 cm near the river mouth and became thinner offshore. The horizontal distributions of the temperature and conductivity at the bottom layer are shown in Fig. 4-2 and Fig. 4-3 respectively. They seem to be complicated patterns. They are associated with bottom topography, which is shown in Fig. 4-4.

The ratio of the river water at the point 70 m apart from the river mouth was 25% in the bottom layer. This value seems to be slight. It means that the river water had been well mixed with the lake water before it reached that point. The ratio did not decrease rapidly offshore from there where the bottom was fairly plane. It means that the vertical mixing is not strong where the bottom slope is slight. Therefore in such a condition the flow may be fairly stable. The mixing of both waters is thought to be dominant while the river water sinks at the river mouth.

The river water sunk mixing around the medium, might be denser yet than the surrounding water, reached the bottom and flowed away along the bottom slope without strong mixing. Such a flow caused by the density difference and the bottom slope may be called the density current. As the lake water was fairly stagnant, such a flow might be stable and balanced as the density current.

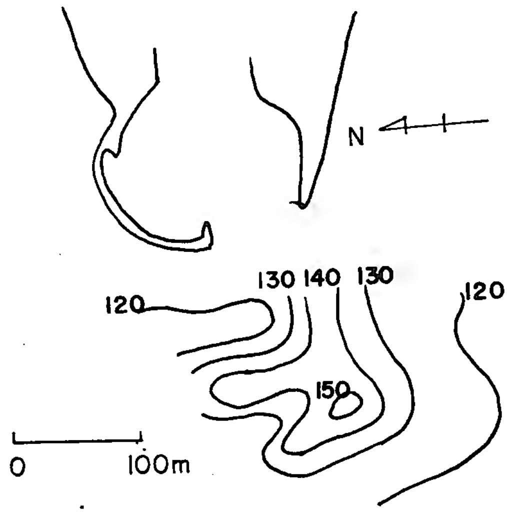

Fig. 4-2 Distribution of conductivity (μ℧/cm) at the bottom on Aug. 19.

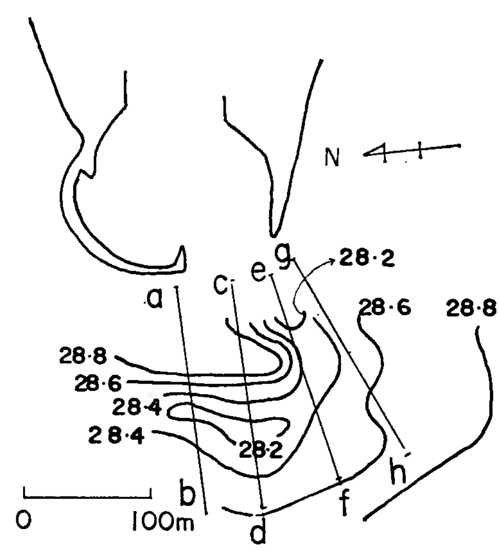

Fig. 4-3 Distribution of water temperature (°C) at the bottom on Aug. 19.

The larger the gradient of the bottom, the larger the pressure gradient of the flow, so the velocity increases. When we consider the bottom friction the vertical shear of the flow becomes large and the flow becomes unstable. The stability of the flow considered the velocity shear, is given by Richardson Number (Ri)

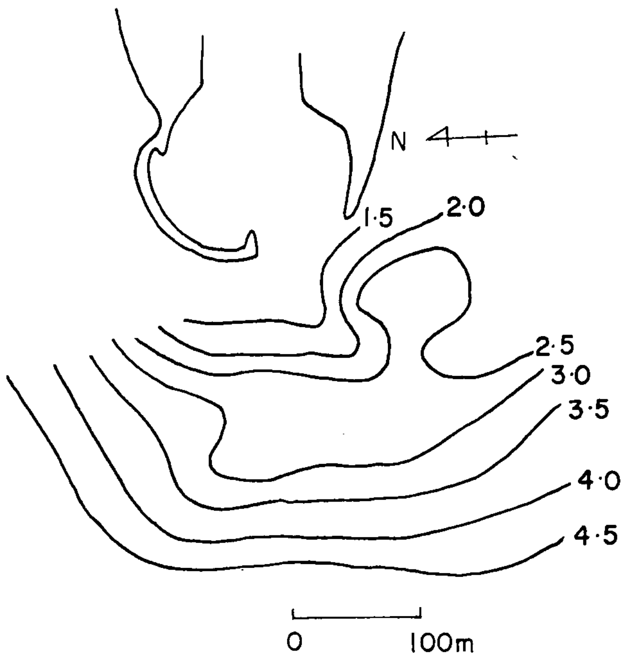

Fig. 4-4 Bottom topography (m).

$$Ri = -\frac{g}{\rho}\frac{\partial \rho}{\partial z} \Big/ \left(\frac{\partial u}{\partial z}\right)^2.$$

The flow is thought to be stable when $Ri > 1/4$ (Taylor (1931)). In our case, if the flow were stable on the fairly plane bottom, how is the velocity? In such conditions that

$$g \sim 10^3 \text{ cm/sec}^2.$$

$$\rho \sim 1 \text{ g/cm}^3.$$

$$\partial \rho / \partial z \sim 1.5 \times 10^{-6} \text{ g/cm}^4.$$

and the velocity is zero at the bottom, the velocity at 50 cm above the bottom is given approximately by

$$u < 4 \text{ cm/sec}.$$

Therefore the mixing may not be facilitated if the flow were in such a condition.

5. Summary

Throughout the present report the dispersion of river water is studied in three cases.

The advective process of the dispersion is in the forms such as the density current which is not always caused by the inflow of the river water but is caused by the temperature distribution in the lake in **Case 1**, the longshore current and the wind driven current in **Case 2**, and the density current caused by the inflow of the river water in **Case 3**.

On the other hand, the diffusive process is not understood well in every case. In **Case 1**, the entrainment, which is thought to be a kind of vertical mixing, is important to the diffusive process but the roles of the horizontal mixing are not known well. In **Case 2**, the outline of such a dispersion may be expressed without considering the diffusion as is treated in this report, but it should be necessary in order for our study progress. In **Case 3**, the turbulent mixing between the river water and the lake water is dominant at the river mouth, and the vertical mixing is facilitated where the bottom slope is large. But it is not known if the process of the mixing is similar to the entrainment.

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