

Hydraulics and Water Quality in Kojima Bay

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Synopsis

In this paper, characteristics of hydraulics and water quality in Kojima Bay are discussed based on field observations. The main results obtained are as follows.

- (1) The variation of flow rate in Kojima Bay has periods for 30 minutes to 2 hours. This characteristic is represented by a two-dimensional numerical simulation fairly well.
- (2) The local distributions of salinity and suspended solids show increase in the direction to the mouth of Kojima Bay. On the other hand, the distribution of COD(Mn) is nearly uniform in the whole area of the bay. Salinity appears to be influenced by river discharge sensitively but suspended solids does not.
- (3) The vertical distributions of salinity and suspended solids are similar. There are similar points between the cross-sectional average of water quality and surface water quality.
- (4) The surface water quality seems to be influenced by the variation of velocity.

1. Introduction

Hydraulics and behavior of pollutants in estuaries and bays

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are very complicated because of tidal action, seiche, river discharges, wastewater effluents and so on.

In this paper, as the first step to clarify the water pollution mechanisms in these waters, characteristics of hydraulics and water quality in Kojima Bay are investigated based on field observations.

The investigation has been carried out since 1977 and is still continuing. We report the results obtained so far. This paper mainly treats with the characteristics of unsteady flow, the local distribution and temporal change of water quality, correlation among water quality items and correlation between the variation of water quality and that of velocity.

2. Study Area

Study area of Kojima Bay is shown in Fig.1, where Asahi River and

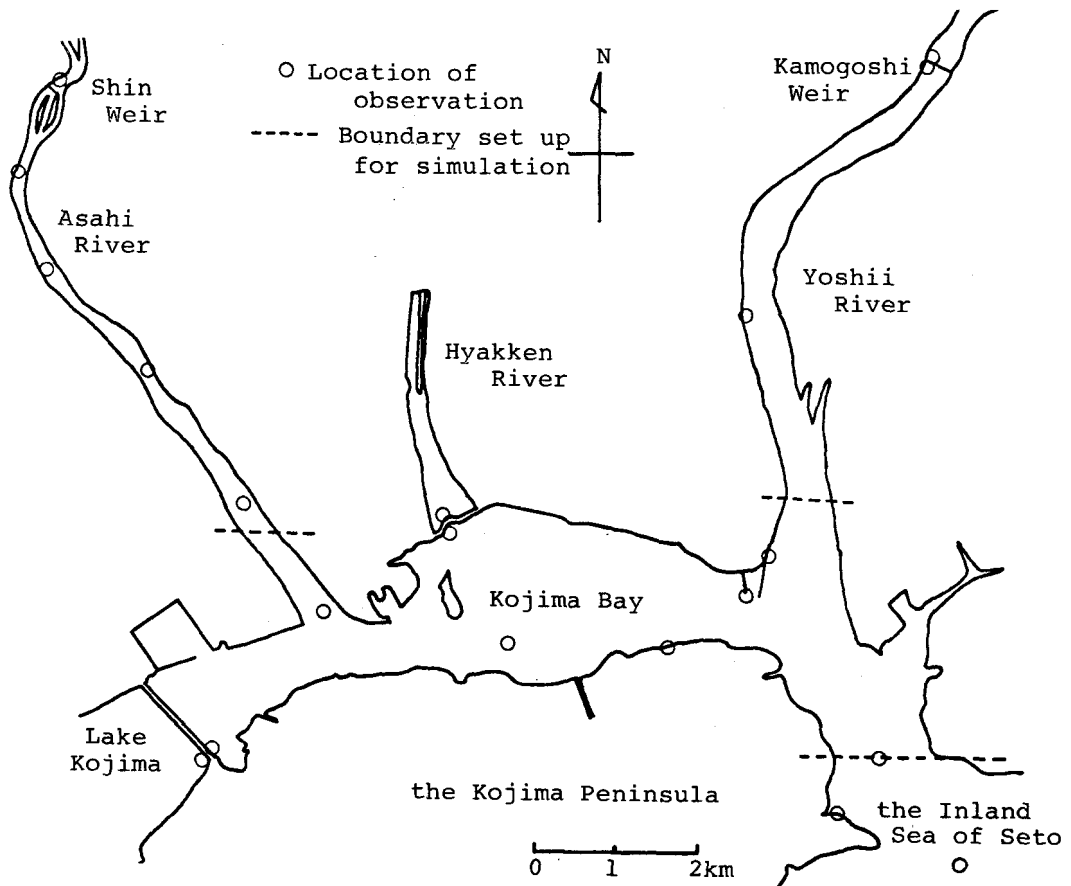


Fig.1 Study area

Yoshii River flow. The width of Kojima Bay is from 1 to 2 km. The south part of that is a waterway and the depth is about 10 m. But in the north part, the waters less than 1 m in depth spread.

Fresh water is discharged from Lake Kojima at the inner part of the bay and Hyakken River at the north part near a low tide.

The tidal portions of Asahi River and Yoshii River are divided by Shin Weir at 7.9km from the river mouth and Kamogoshi Weir at 7.3km respectively. The upstreams of both weirs are non-tidal portions. The annual averages of both river discharges are approximately $60\text{m}^3/\text{s}$.

The areas of Kojima Bay and the tidal portions of both rivers are about 15km^2 and 5km^2 respectively. The average of the spring tide range at Kojima Bay is 1.34m. Along the both rivers and the coast of the bay, there are several industrial factories and a outlet of a sewage treatment plant.

3. Methods of Field Observations

The locations of field observations are shown in Fig.1. The broken lines in this figure represent boundaries which are set up for the numerical simulation of hydrodynamics in Kojima Bay.

The locations and the durations of observations, the intervals of sampling and the intervals of measuring tidal level and velocity are not always the same because the importance of observation is somewhat different according to observation. The outline of observations is as follows.

The observations are classified into two kinds according to the method of water sampling; the observations of surface water in the whole area of Kojima Bay and the observations in which sampling of water was carried out at several verticals in the tidal portion of Asahi River or the waterway of Kojima Bay.

In the former, the hourly sampling of surface water and measuring of tidal level at intervals of 10 or 30 minutes were carried out for 24 hours. In the latter, sampling of water and measuring velocity were carried out at 1m vertical interval. In this case the time intervals of measuring velocity and tidal level were from 15 minutes to an hour and from 10 to 30 minutes respectively.

Water samples collected were returned to the laboratory on the same day. The water quality items analysed are chemical oxygen demand by potassium permanganate COD(Mn), suspended solids SS and salinity S. COD(Mn) was measured by alkali method, SS by glass fiber filter and

S from electric conductance.

4. Mathematical Model for Unsteady Flows in Kojima Bay

The hydrodynamics in Kojima Bay was obtained from the two dimensional equations of motion and continuity. The basic equations of motion for two dimensional unsteady flow are

$$\begin{aligned} & \partial(hu)/\partial t + \partial(hu^2)/\partial x + \partial(huv)/\partial y + gh\partial\zeta/\partial x \\ = & fhv + \frac{1}{\rho}(\tau_x^s - \tau_x^b) + \frac{1}{\rho} \left\{ \frac{\partial(hAx\partial u/\partial x)}{\partial x} + \frac{\partial(hAy\partial u/\partial y)}{\partial y} \right\} \end{aligned} \quad (1)$$

and

$$\begin{aligned} & \partial(hv)/\partial t + \partial(huv)/\partial x + \partial(hv^2)/\partial y + gh\partial\zeta/\partial y \\ = & -fhu + \frac{1}{\rho}(\tau_y^s - \tau_y^b) + \frac{1}{\rho} \left\{ \frac{\partial(hAx\partial v/\partial x)}{\partial x} + \frac{\partial(hAy\partial v/\partial y)}{\partial y} \right\} . \end{aligned} \quad (2)$$

The equation of continuity can be expressed as

$$\partial\zeta/\partial t + \partial(hu)/\partial x + \partial(hv)/\partial y = 0 , \quad (3)$$

- where, h; height from the bottom to the reference level,
- ζ; water surface elevation with respect to the reference level,
- u,v; velocity components in x and y directions,
- f; Coriolis parameter,
- Ax, Ay; momentum dispersion coefficients in x and y directions,
- τ_i^b, τ_i^s ; shear stresses at surface and bottom in i direction.

A space-staggered grid shown in Fig.2 was selected for the finite-difference approximation of Eqs. (1) through (3) [1,2]. The relative position of the variables in the model is shown in Fig.3.

The boundary conditions applicable to the numerical simulation are as follows. At the mouth of Kojima Bay tidal level is applied. At the mouths of Asahi River and Yoshii River, Kojima Bay is assumed to be connected with two reservoirs

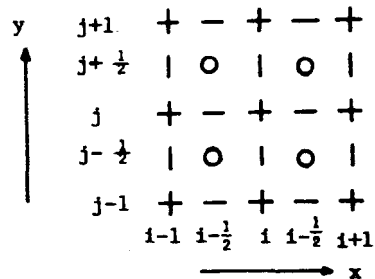
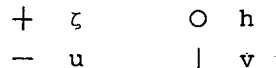


Fig.2 Space-staggered grid



which have each surface area equal to that of the tidal portion of each river.

For the simulation Coriolis parameter of 0.00008rad/s and momentum dispersion coefficients in x and y directions of $10^5 \text{ cm}^2/\text{s}$ were selected. Besides, with reference to shear stresses following

formulae and values were selected; τ_1^s of zero, $\tau_x^b = \rho r b^2 u \sqrt{u^2 + v^2}$, $\tau_y^b = \rho r b^2 v \sqrt{u^2 + v^2}$ and $r b^2$ of 0.0026.

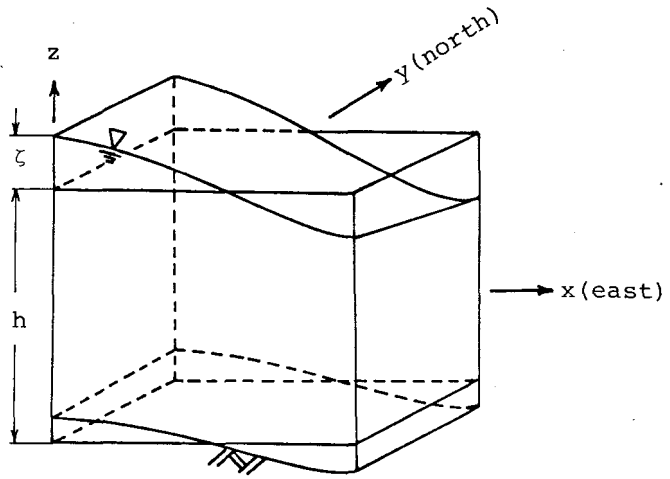


Fig.3 Schematic showing coordinate

5. Results and Discussions

5.1 Hydraulics in Kojima Bay

The tidal level and flow rate obtained by the simulation at the mouth of Asahi River are shown in Fig.4 and Fig.5 in comparison with measured values respectively. The simulation result of the tidal level shows good agreement with the measured values. With reference to the flow rate, the measured values are characterized by the variation

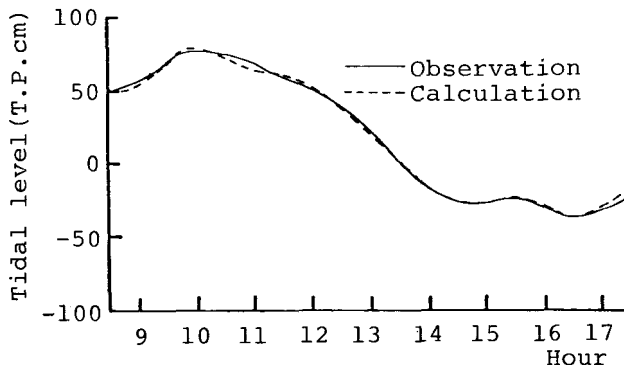


Fig.4 Tidal level at the mouth of Asahi River

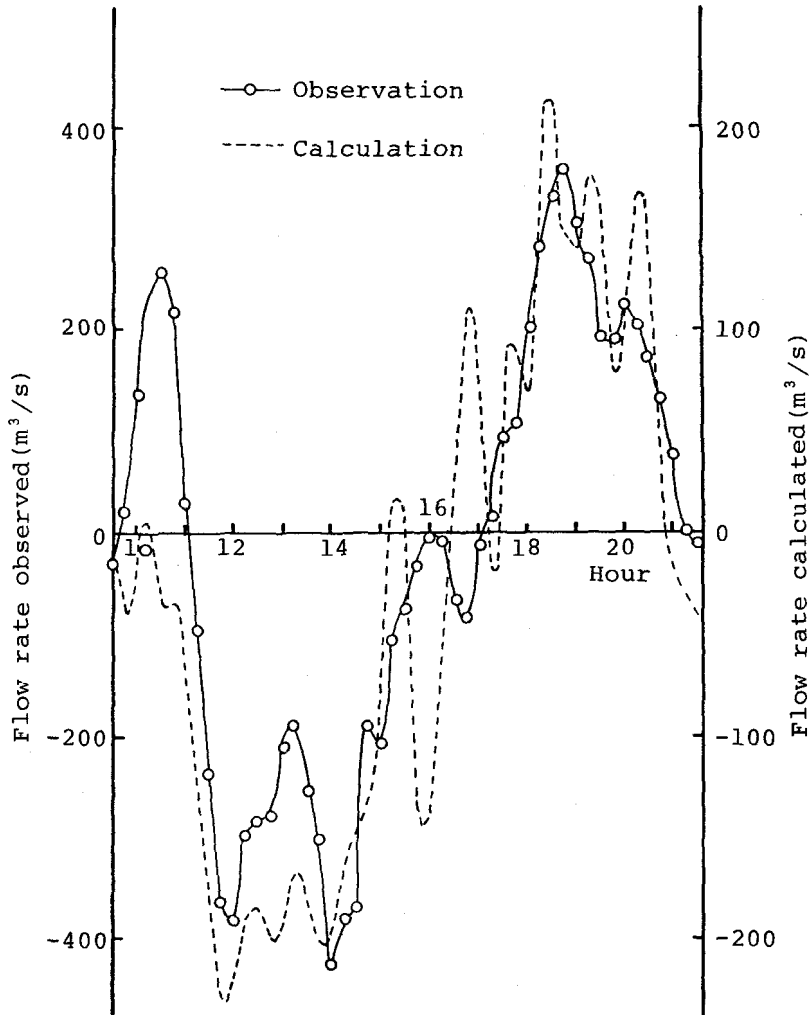


Fig.5 Flow rate at the mouth of Asahi River

which has periods from a half hour to 2 hours. The result of the simulation can explain this tendency fairly well. However, with reference to the absolute values considerably large differences are found between the results of the simulation and the observation. The answer to this cause is considered as follows. The results of simulation represent approximately cross-sectional averages. On the other hand, the measured values shown in Fig.5 are obtained by means of multiplying the average velocity at the vertical in the waterway by the cross-sectional area. Since the average velocity at the waterway is considered to be higher than the cross-sectional average velocity, the measured values may consequently be larger than the results of simulation.

As above-mentioned, the results of the simulation are recognized to explain the hydrodynamics in Kojima Bay fairly well. We accordingly describe the characteristics of hydrodynamics in Kojima Bay according to the results of the simulation in the next place.

Fig.6 and Fig.7 show the spatial distributions of velocity components on the flood tide and the ebb tide seen in Fig.4 respectively. In these figures the flow rates at the cross-sections shown by the broken lines are noted down.

The Change of the flow rate at the mouth of Kojima Bay nearly ranges between $-1900\text{m}^3/\text{s}$ and $1100\text{m}^3/\text{s}$. That at the mouth of Asahi River nearly ranges between $-160\text{m}^3/\text{s}$ and $160\text{m}^3/\text{s}$. The average inflow rates from both Asahi River and Yoshii River were about $10\text{m}^3/\text{s}$ during the observation.

Fig.8 shows the temporal changes of tidal levels at the mouths of Asahi River , Yoshii River and Kojima Bay. The changes of the tidal levels at the mouths of Asahi River and Yoshii River show different shapes from that at the mouth of Kojima Bay near the low tide and high tide.

The temporal changes of flow rates are shown in Fig.9. The changes of the flow rates except that at the mouth of Kojima Bay have periodic variations from 15 minutes to 2 hours.

The hydrodynamics in Kojima Bay is complicated in the way described above. This complication is considered to be caused by topographical factors of the bay.

So far, the characteristics of the two-dimensional hydrodynamics have been outlined. However, the actual distribution of velocity changes in the vertical direction considerably. The details of the velocity distribution are described together with that of water quality

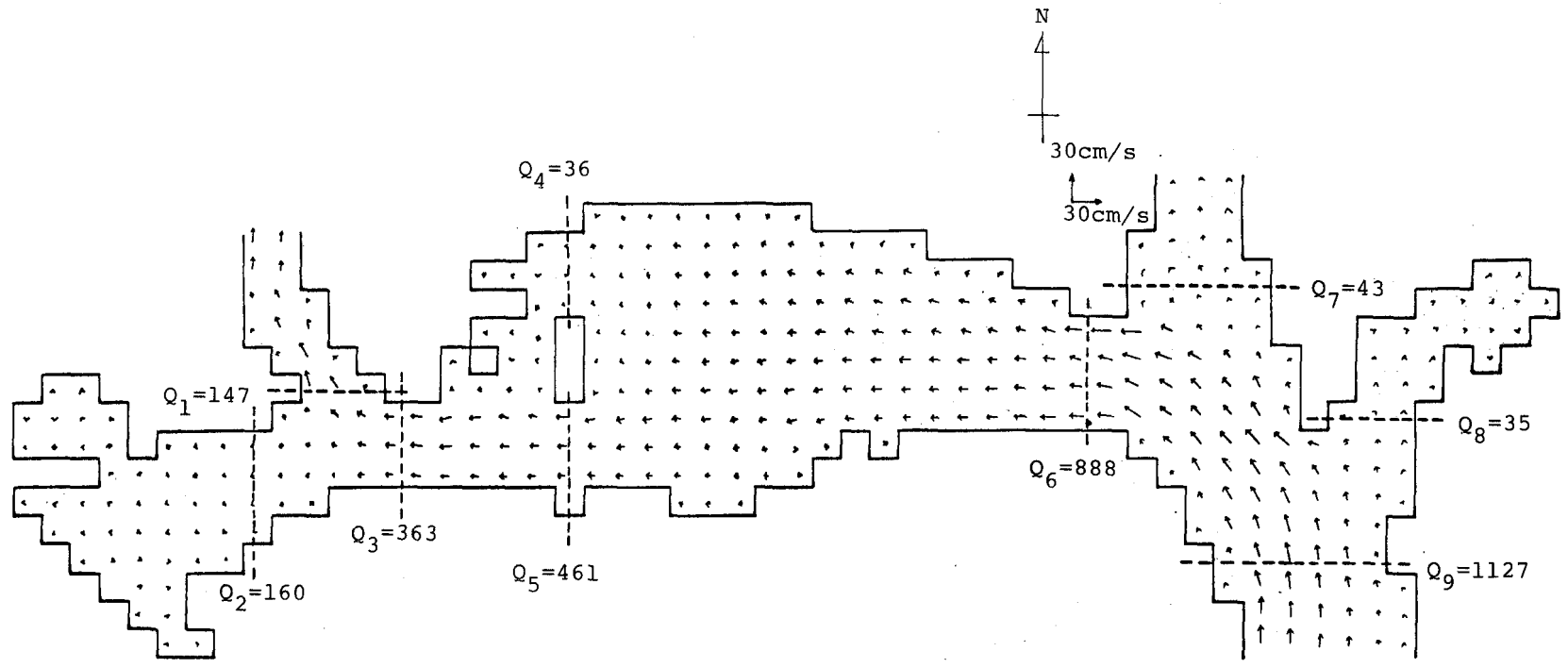


Fig.6 Distribution of velocity components on the flood tide

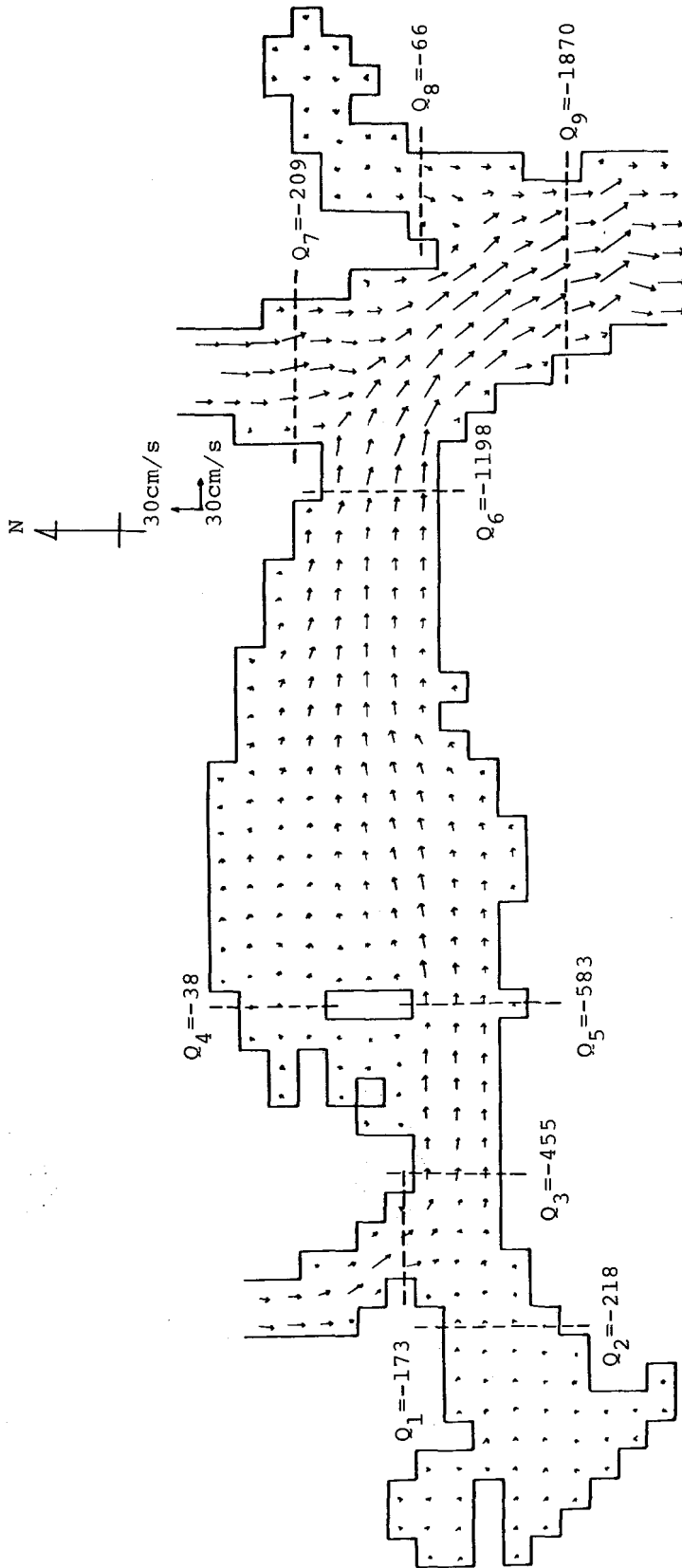


Fig.7 Distribution of velocity components on the ebb tide

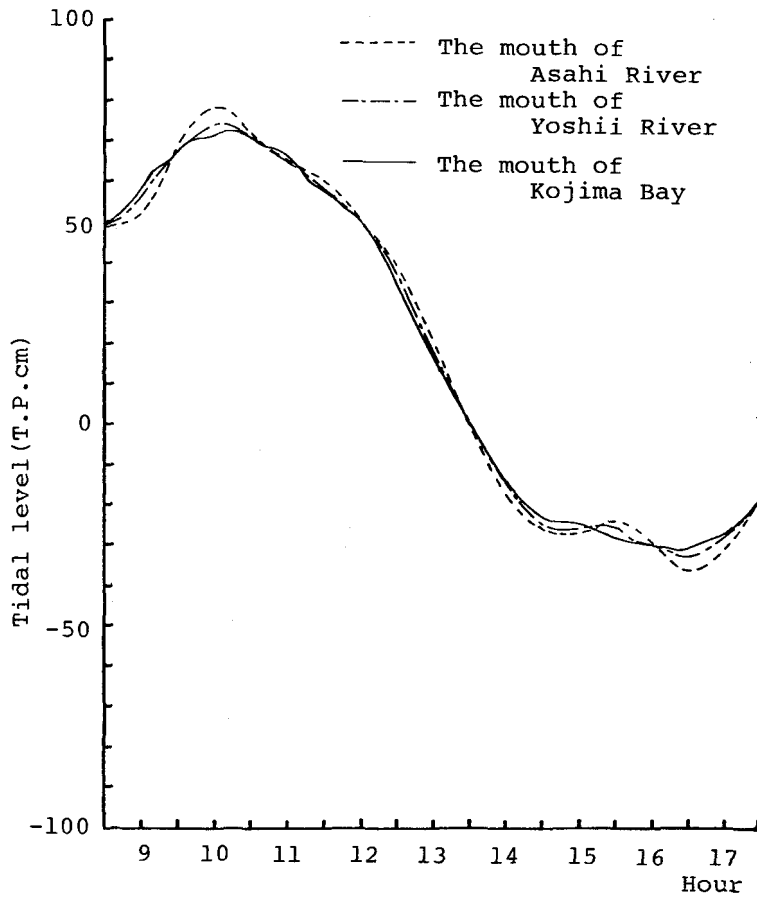


Fig.8 Tidal levels at the mouths of Asahi River, Yoshii River and Kojima Bay

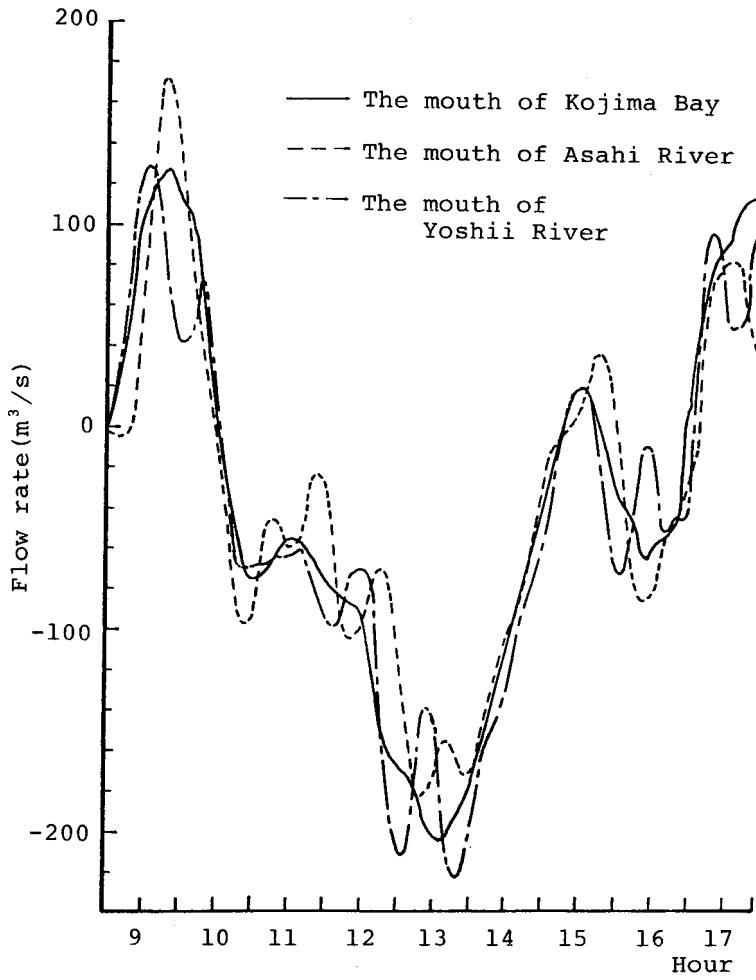


Fig.9 Flow rates at the mouths of Asahi River, Yoshii River and Kojima Bay

in the later section.

5.2 Characteristics of Water Quality

5.2.1 Local Distribution of Temporal Mean

Fig.10, Fig.11 and Fig.12 show the distributions of S, SS and COD(Mn) along the waterway from the upper end of Asahi River estuary, Shin Weir, to the mouth of Kojima Bay. Since the concentration of each water quality at each location considerably fluctuated with time, averages for one tidal cycle or two tidal cycles are shown in these figures.

Fig.10 and Fig.11 show that both S and SS increase in the direction to the mouth of Kojima Bay. Concerning the effect of discharge from Asahi River, S appears to be affected sensitively but SS does not so. The discharges from Yoshii River were nearly the same as those from Asahi River.

As in Fig.12, COD(Mn) seems to

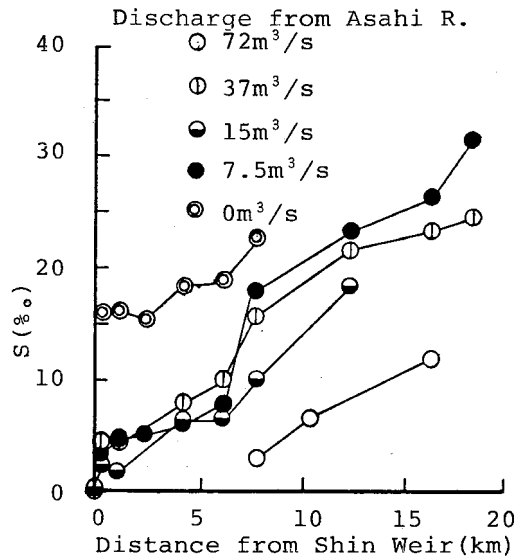


Fig.10 Distribution of S

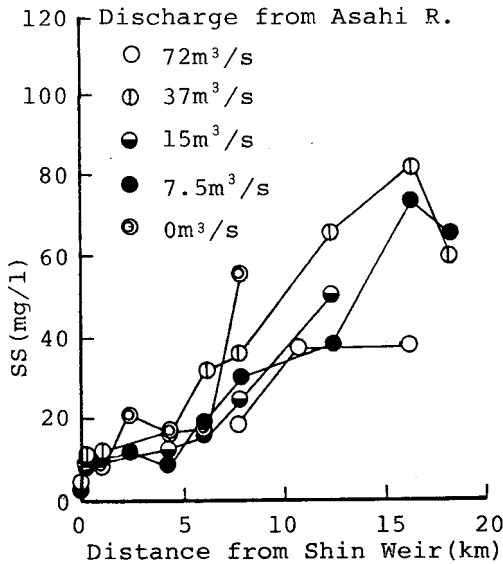


Fig.11 Distribution of SS

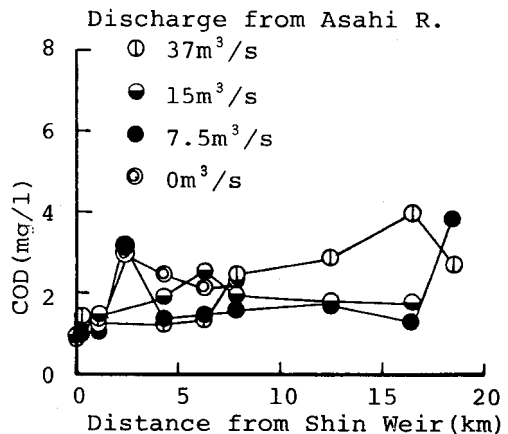


Fig.12 Distribution of COD(Mn)

be nearly uniform. But COD(Mn) in Asahi River appears to become relatively high when the discharge decreases.

5.2.2 Cross-Sectional Average of Water Quality and Surface Water Quality

Fig.13 shows cross-sectional average concentrations and surface concentrations at typical four locations selected from the observation area. The data at the locations except Asahi River Bridge were obtained at the same observation.

Regarding the relationship among each location and the tendency of the temporal change, many similar tendencies are found between the cross-sectional average concentrations and the surface concentrations. However, both kinds of concentrations do not always show the similar

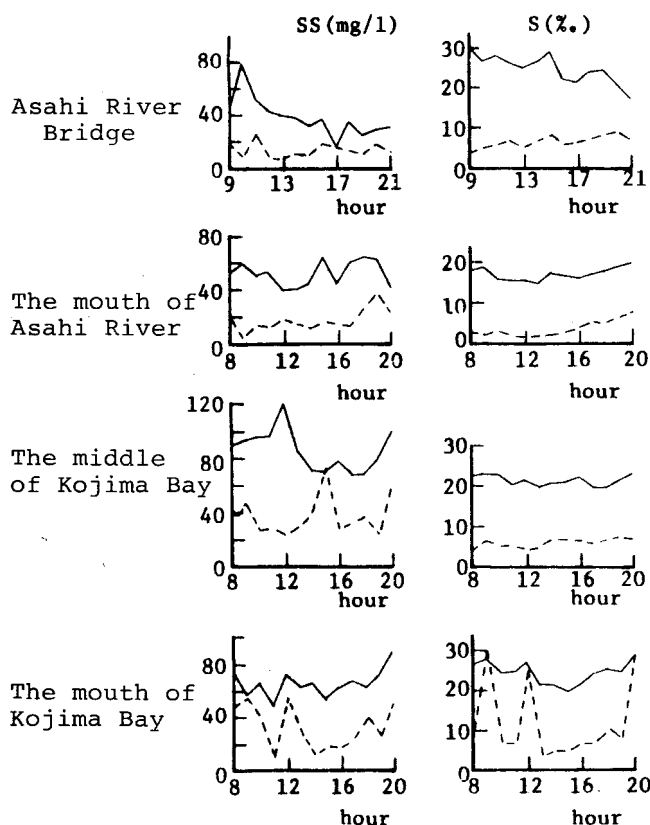


Fig.13 Cross-sectional average of water quality and surface water quality
 — Cross-sectional average
 ---- Surface water

changes.

5.2.3 Vertical Distribution of Water Quality

Fig.14 shows the vertical distributions of velocity, S and SS at the mouth of Asahi River. The distributions are complicated. Flow reversals at depth are found near the high tide and low tide. S and SS show similar increase from the surface to the bottom however they are different from each other in the smoothness of the increase. SS often has large peaks but S smoothly increases.

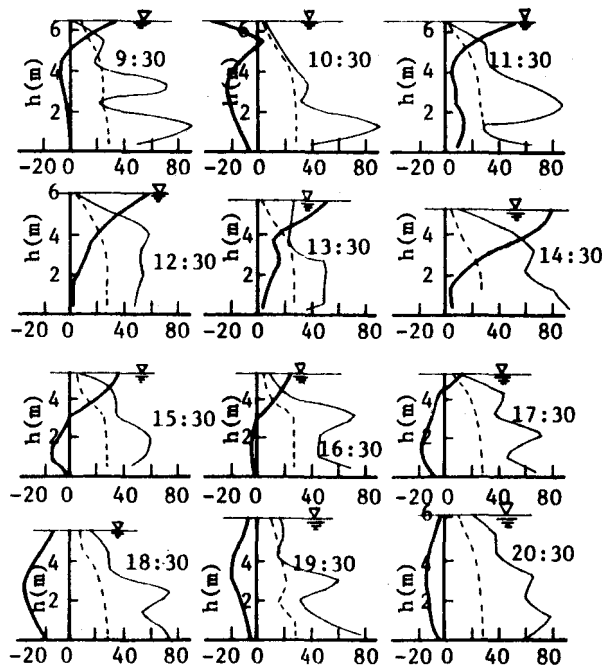


Fig.14 Vertical distribution of velocity,
 S and SS at the mouth of Asahi River
 — Velocity (cm/s)
 ---- S (‰)
 —·— SS (mg/l)

5.2.4 Variation of Water Quality

Fig.15 shows the variations of tidal level, SS, S and COD(Mn) at

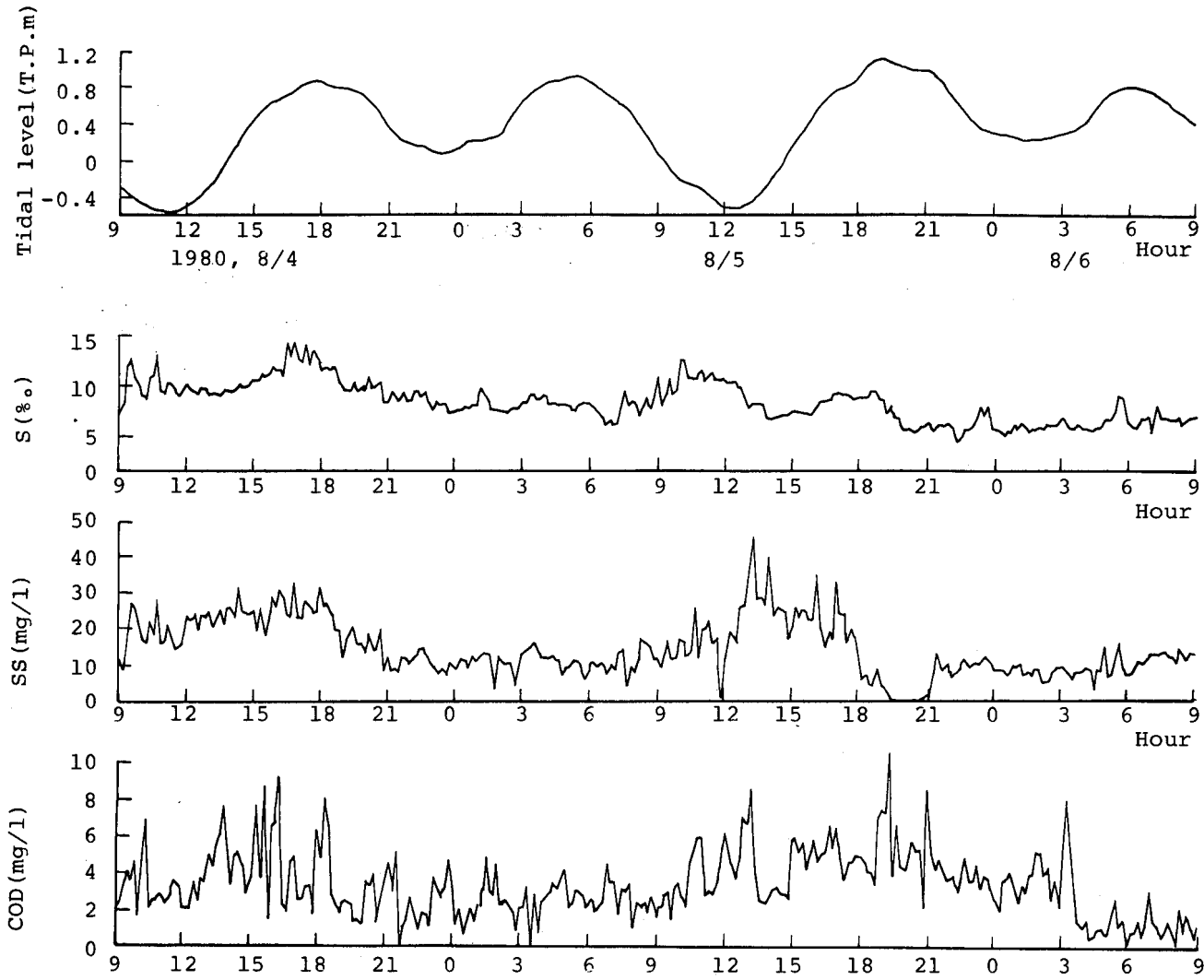


Fig.15 Variations of tidal level, S, SS and COD(Mn)

the mouth of Asahi River. The intervals of sampling and measurement are 10 minutes. The variations of the water quality seem to have some periods.

The power spectra calculated from these variations are shown in Fig.16, Fig.17 and Fig.18. S is found to have peaks which represent periods for about 2 hours, 80 minutes and 50 minutes, SS for about 4 hours, 2 hours, 80 minutes, 60 minutes and 30 minutes. COD(Mn) has many peaks besides those described above. These peaks are not always

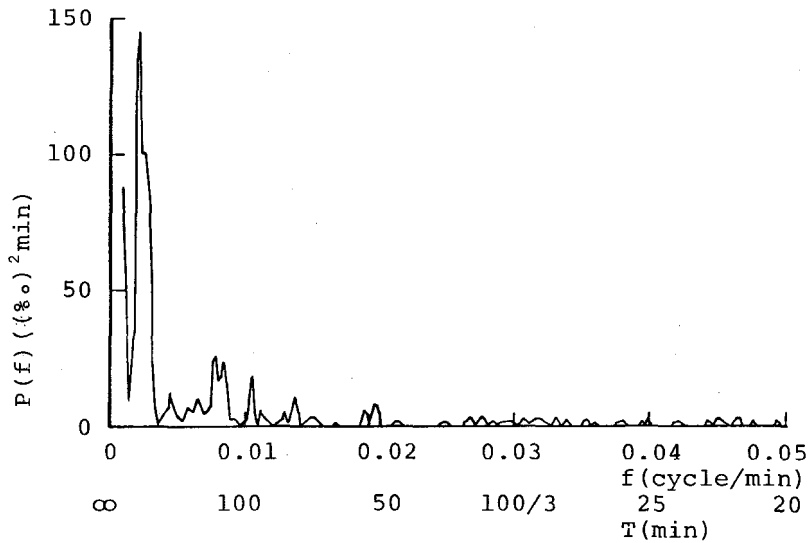


Fig.16 Power spectrum of S

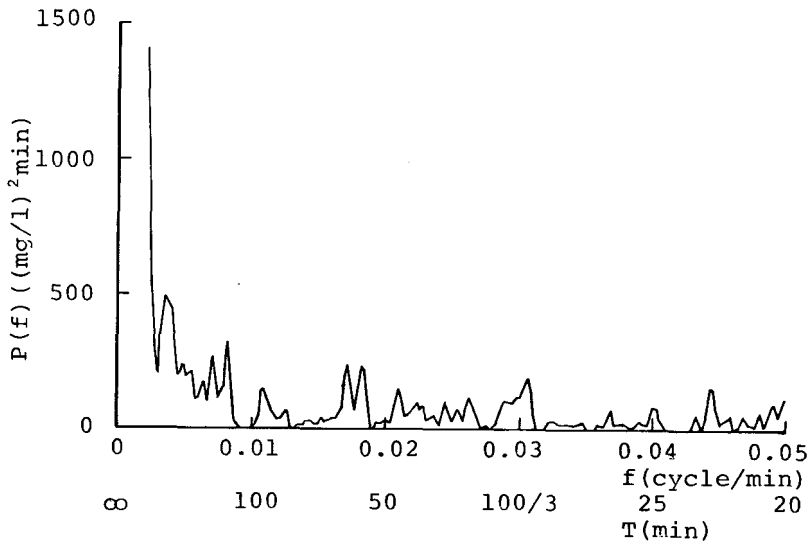


Fig.17 Power spectrum of SS

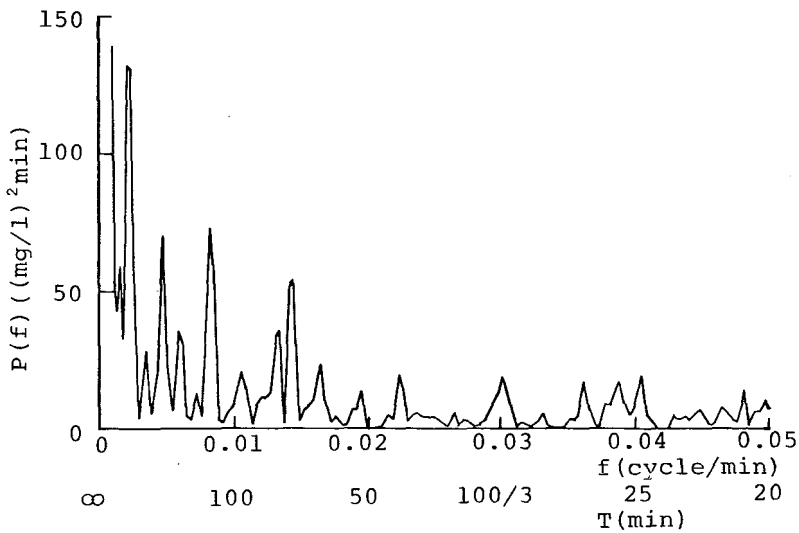
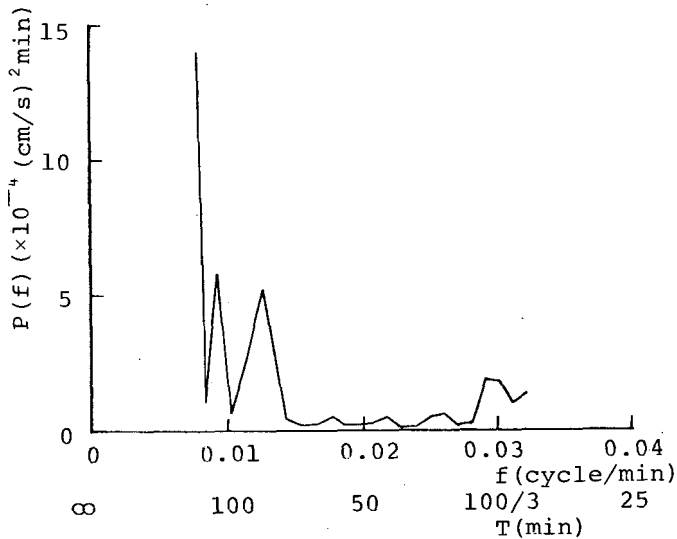


Fig.18 Power spectrum of COD(Mn)



notable, but the periods for about 2 hours and 80 minutes are in common with three water quality items.

Fig.19 shows the power spectrum of velocity calculated from the data shown in Fig.5. The peaks of periods for about 2 hours, 80 minutes and 30 minutes are found. The peaks for 2 hours and 80 minutes are found in all water quality items, too. Besides, the peak for 30 minutes is found in SS. The variation of the flow rate or velocity seems to

have an effect on the variations of surface water quality.

6. Conclusions

In this paper, as the first step to clarify water pollution mechanisms in estuaries and bays, the characteristics of hydrodynamics and water quality in Kojima Bay are investigated based on field observations. The summary of the main results obtained is as follows.

- (1) The variation of flow rate or velocity in Kojima Bay has the periods from 30 minutes to 2 hours besides a tidal cycle. This characteristic of flow is represented by a two-dimensional numerical simulation fairly well.
- (2) The local distributions of S and SS show the increase in the direction to the mouth of Kojima Bay. On the other hand, the distribution of COD(Mn) is rather uniform in the whole area of the bay. S appears to be affected by river discharge sensitively but SS does not.
- (3) The vertical distributions of S and SS are similar, and there are similarities between the cross-sectional averages of water quality and the surface water quality concerning the relationship between each location and the tendency of the temporal change.
- (4) The variations of the surface water quality at the mouth of Asahi River show common periods for about 2 hours and 80 minutes. The velocity has the same periods, too. Therefore, it will be concluded that the surface water quality is influenced by the variation of velocity.

Thanks are due to our colleagues who contributed their sustained efforts and grasp of objectives to the accomplishment of the observation programs. We should like to express our grateful thanks to the public officials who extended us their kind assistance.

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