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Preliminary research on salinity and flow rate profiles of a river with an estuarine zone by the analysis of water quality monitoring data

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Abstract: The published studies related to hydrodynamic, hydrologic and pollutant loads especially in the fields of rivers and estuaries were briefly summarized. Salinity in the upper and the bottom layers, and flow rate at the monitoring point near the river mouth of the Ebigawa River, Chiba Prefecture, Japan, were analyzed with tidal level fluctuation at the Chiba Port as a preliminary study for the development of a hydrodynamic and water quality model in the estuary segment of the Ebigawa River. Contour lines and anthropogenic water contribution to water flow were analyzed. Defining contour line patterns could enhance understanding of the flow and salinity patterns in the estuarine zone of the river. It was qualitatively confirmed that the tidal level fluctuation, fresh water inflow, and anthropogenic water influenced the salinity and flow rate at the monitoring point.

Key words: inner-city river, estuary, salinity wedge, tidal level, anthropogenic water

1 Introduction

River-mouth is consisted of fresh water flowing from the river and salt water from the sea. Because the movements of both these flows are complex, it is desirable to consider as two-layer flow in calculating pollutant loads at and/or near the river-mouth. The flows near the river-mouth are divided into three mixture patterns depending on the intensity of turbulence and mixture: 1) strong mixture, 2) moderate mixture, and 3) weak mixture (Fig. 1) (Tamai, 1980). In the case of strong mixture, water density is equal with the vertical direction and only horizontal water density gradient exists. In the case of moderate mixture, both vertical and horizontal water density gradient exist. In the case of weak mixture, fresh water in the upper layer and salt water in the bottom layer do not mix so much and make a definite layers, which is called salt wedge.

When the cross-section can be supposed not to be changed in the simulation model for strong mixture, salinity in the cross-section is considered as the same and the flows can be simplified as one-dimension model with x-axis as the longitudinal direction.

A lot of hydrodynamic/hydraulic models have been developed to describe circulation, mixing and density stratification which can affect water quality and pollutant movement within a water body. These models are classified with their spatial dimensions: 1) one-dimension longitudinal models, 2) two-dimensional in the longitudinal and vertical, 3) two-dimensional in the horizontal (vertically averaged), and 4) fully three-dimensional. Some hydrodynamic/hydraulic models developed in the United States are shown in Table 1. In Japan, some hydrodynamic/hydraulic models have been developed by academics, business, and national level institutes including the Public Works Research Institute, the Industrial Science Institute, the National Institute of Environmental Science and so on.

Some hydrodynamics, hydrologic and pollutant loads related researches have been conducted in the Ebigawa River drainage area (Fig. 2), Chiba Prefecture, Japan, using rain-runoff and water quality models. Herath and Musiake (1994) conducted study on water circulation in the Ebigawa River drainage area with monitoring data of

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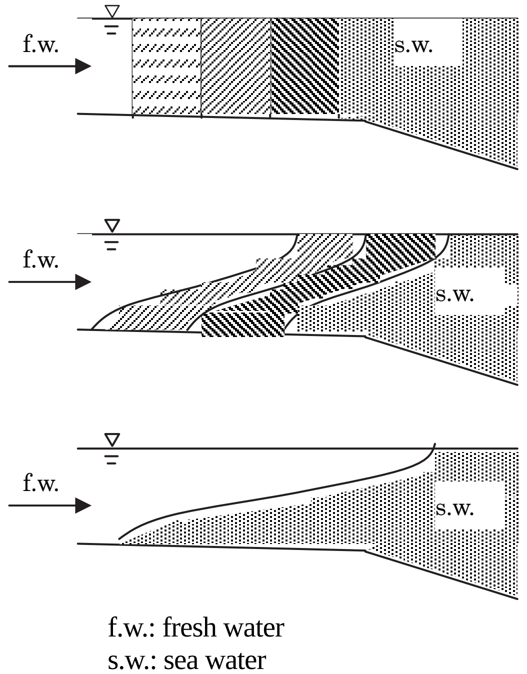

Fig. 1. Types of density flows in the estuary near the river mouth: a) strong mixture, b) moderate mixture, and c) weak mixture. (prepared by the author after Tamai, 1980)

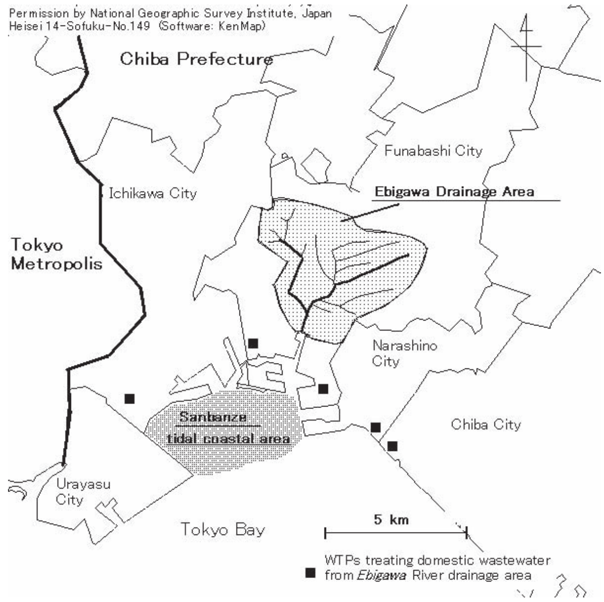

Fig. 2. The drainage area of the Ebigawa River, Chiba Prefecture, Japan. (Tsuzuki, 2004)

precipitation, flow rate and water level of rivers, ground water level, water contents of soils, meteorology data and so on. They found large contribution of anthropogenic water and wastewater (water and wastewater related to human activities) from households, factories and offices to total water balance in the drainage area. Anthropogenic water supply and wastewater amounts were calculated as 636 mm y^{-1} and 105 mm y^{-1} in contrast to 1,468 mm y^{-1} precipitation in 1993. Yangwen et al. (2001) modified a distributed hydrology model, Water and Energy Transfer Process (WEP) model, to study the effects of storm-water detention facilities in the Ebigawa River drainage area. Tsuzuki (2004) investigated the Ebigawa River of public monitoring data, estimated pollutant loads flowing into the Tokyo Bay through the Ebigawa River for BOD, COD, TN and TP originated from domestic wastewater and recommended to prepare and use environmental accounting housekeeping (EAH) books for domestic wastewater in order to reduce pollutant discharges from households. Yamazaki et al. (2005) modified a distributed runoff model based on the kinetic wave method by incorporating the interflow component in a synthesized manner in three urban river drainage areas including the Ebigawa River drainage area.

The aim of this study is to briefly summarize hydrodynamic, hydrologic and pollutant loads related studies in the estuarine zone of the river, and to investigate the salinity in the upper layer and the bottom layer at Yachiyo Bashi Bridge monitoring point, nearest to the river mouth, with tidal level fluctuation as a preliminary study for the development of hydrodynamic and water quality models in the estuary segment of the Ebigawa River. Simple calculation of pollutant loads near the river mouth by use of public monitoring water quality, flow rate and tidal level data could be achieved based on the summarization. Flow rate and salinity in the estuarine zones of a inner-city river are considered to be dependent on fresh water flow from upper stream and tidal flow from lower stream. In this study, the influence of fresh water flow and tidal flow are qualitatively summarized based on the public monitoring data.

William (1972) writes in the preface that "designing and testing indicators of environmental quality are not mere academic exercises - scientists have a responsibility to make 'environment' comprehensible to all segments of society that justifiably demand a greater participatory role in determining the habitability of our planet." Hackes (1972) insisted the importance for members of the environmental science community to come forward with environmental indices .... to explain their ecological concerns to the public at large .... Public participation and corporation of the stakeholders in the field of preservation of environment is being highlighted in these days in Japan also, and Natural Rehabilitation Promotion Act was enacted in 2004. Huge amounts of environmental monitoring data including water quality have been monitored especially in the developed countries including Japan. Showing what can be understood from the public monitoring data is one of the roles of members in the environmental science community as suggested by Hackes (1972). The author used public monitoring data from this point of view.

Table 1. Examples of hydrodynamic / hydraulic model (U. S. Army Corps of Engineers, 2005)

Model	Description	Steady State/ Dynamic	Dimension	Supporting Agency/ Developer
CE-QUAL-RIV1*	Hydrodynamic & Water Quality Model for Streams	Dynamic	1-D	USACE
CE-QUAL-W2*	2D Laterally-averaged Water Quality Model	Dynamic	2-D vertical	USACE
CH3D-WES*	Curvilinear Hydrodynamics in Three Dimensions – Waterways Experiment Station	Dynamic	3-D	USACE
CORMIX	A mixing-zone model	Steady State	3-D	USEPA
DYNHYD5	Link-Node Tidal Hydrodynamic Model	Dynamic	1-D	USEPA/CEAM
ECOMSED	Hydrodynamic and Sediment Transport Model	Dynamic	3-D	HydroQual, Inc.
EFDC*: Environmental Fluid Dynamics Code	Hydrodynamics and transport model	Dynamic	1-D to 3-D	Tetra-Tech/Virginia Institute of Marine Sciences
HEC-2/HECRAS*	River Analysis System	Steady State	1-D (HEC-2)	USACE/ HEC
HEM1D/HEM2D/ HEM3D	Hydrodynamic Eutrophication Model	Dynamic	1-D to 3-D	Virginia Institute of Marine Science
HSCTM-2D	Hydrodynamic and Sediment and Contaminant Transport Model	Dynamic	2-D lateral	USEPA/CEAM
MIKE-11/MIKE-21/MIKE-3*	Generalized Modeling Package-1D/ 2D/3D - Hydrodynamics	Dynamic	1-, 2- and 3-D	Danish Hydraulic Institute
POM	Princeton Ocean Model	Dynamic	3-D	Princeton University
RIVMOD-H	River Hydrodynamic Model	Dynamic	1-D	USEPA/CEAM
RMA-2V*	Hydrodynamic analysis model	Dynamic	2-D lateral	WES
UNET	1-D Unsteady Flow through a Full Network of Open Channels	Dynamic	1-D	USACE

2 Basic concepts and formulas of density flow

A series of basic concepts and formulas are summarized by e.g. Bowden (1967), Tamai (1980) and Okuda (1996). In this section, their texts were briefly summarized focusing on the basic concepts of the salinity and flow rate in the estuaries of rivers.

Bowden defined five types of estuarine circulation: 1) salt wedge estuary, 2) two-layer flow with entrainment, including fjords, 3) two-layer flow with vertical mixing, 4) vertical homogeneous (a) with lateral variation, and (b) laterally homogeneous, and 5) exceptional cases such as intensive, mixing in restricted sections, tributary estuaries, sounds straits (Table 2).

Basic principles controlling circulation and mixing in the estuarine zones in the rivers are expressed by the equations of motion of the water and the equations of continuity of water and mass of salt (Bowden, 1967).

Let x-axis to be longitudinal direction and y-axis to be across the river, and z-axis to be vertical direction. Let u, v, w, to be the components of mean velocity at the point (x, y, z) at time t. Then, Equations of motion are expressed as:

$$\frac{Du}{Dt} - fv = -\alpha\left\{\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}\right\} \tag{1}$$

$$\frac{Du}{Dt} - fu = -\alpha\left\{\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z}\right\} \tag{2}$$

$$0 = -\alpha\frac{\partial p}{\partial z} + g \tag{3}$$

Table 2. Types of estuarine circulation (modified by the author after Bowden, 1967,)

	Type	Physical processes	Forces
1	Salt wedge	River-flow dominant	Pressure gradients, field accelerations, coriolos effect, interfacial friction
2	Two-layer flow with entrainment, including fjords	River-flow, modified by tidal currents	Pressure gradients, field accelerations, coriolis effect, entrainment
3	Two-layer flow with vertical mixing	River-flow and tidal mixing	Pressure gradients, field accelerations, coriolis effect, turbulant shear stresses
4(a)	Vertical homogeneous with lateral variation	Tidal currents predominating	Pressure gradients, field accelerations, turbulant shear stresses, coriolis effect
4(b)	Vertical homogeneous laterally homogeneous	Tidal currents predominating	Pressure gradients, field accelerations, turbulant shear stresses
5	Exceptional cases: intensive mixing in restricted sections, tributary estuaries, sound, straits etc.		

where $(D / Dt) = (\partial / \partial t) + [u (\partial / \partial x)] + [v (\partial / \partial y)] + [w (\partial / \partial z)]$; f: Coriolis parameter ($= 2\omega \sin \phi$); p: pressure at (x, y, z); α: specific volume ($= 1 / \rho$), ρ: density; g: gravity acceleration; τ_{xy}: stress on a plane perpendicular to x-axis acting in the y-axis direction.

The equation of continuity of volume is:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{4}$$

The equation of conservation of salt may be written:

$$\frac{Ds}{Dt}=\frac{\partial}{\partial x}(K_x\frac{\partial S}{\partial x})+\frac{\partial}{\partial y}(K_y\frac{\partial S}{\partial y})+\frac{\partial}{\partial z}(K_z\frac{\partial S}{\partial z}) \tag{5}$$

where Kx, Ky and Kz: coefficients of eddy diffusion in the x, y, z directions, respectively. The solution of the estuarine circulation problem would involve solving the equations (1) to (5) in the conditions of typical estuarine zones of the rivers.

When considering on the two-layer flow, components of upper layer expressed with suffix 1 and lower layer with suffix 2, the equation of conservation of volume are expressed (Tamai, 1980):

$$\frac{\partial}{\partial t}(s-h)+\frac{\partial}{\partial x}u_1(s-h)+\frac{\partial}{\partial y}v_1(s-h)=Eq \tag{6}$$

$$\frac{\partial}{\partial t}(h-b)+\frac{\partial}{\partial x}u_2(h-b)+\frac{\partial}{\partial y}v_2(h-b)=-Eq \tag{7}$$

where s: z-coordinate of water surface; h: z-coordinate of boundary; b: z-coordinate of bottom; E: entrainment coefficient; q: absolute of velocity difference of upper and lower layer expressed:

$$q=\begin{cases}+\sqrt{(u_1-u_2)^2+(v_1-v_2)^2}\left(when\sqrt{u_1{}^2+v_1{}^2}>\sqrt{u_2{}^2+v_2{}^2}\right)\\ -\sqrt{(u_1-u_2)^2+(v_1-v_2)^2}\left(when\sqrt{u_1{}^2+v_1{}^2}<\sqrt{u_2{}^2+v_2{}^2}\right)\end{cases} \tag{8}$$

Supposing the water density distribution to be uniform, ρ_2 (=const.) in the lower layer and linear relationship in the upper layer, water density in the upper layer ρ is expressed:

$$\rho(z)=\rho_s+(\rho_2-\rho_s)\frac{s-z}{s-h} \tag{9}$$

where ρs: water density at the surface.

The averaged water density in the upper layer is the average of ρ_s and ρ_2. The equation of conservation of mass is only for upper layer because the water density of lower layer to be uniform:

$$\frac{\partial\rho_1}{\partial t}+U_1\frac{\partial\rho_1}{\partial x}+V_1\frac{\partial\rho_1}{\partial y}=\frac{K}{s-h}\nabla_h{}^2\rho_1(s-h)+\frac{\rho_2-\rho_1}{s-h}Eq \tag{10}$$

where K: horizontal eddy kinematic diffusion coefficient; and

∇_h^2: Laplacian in the horizontal plane ($=\partial^2/\partial x^2+\partial^2/\partial y^2$);

The equations of motion in the upper layer and lower layer presented by Tamai (1980) were complicated and are not shown in this paper.

Okuda (1996) explained basic principles of two-layer flow especially salt wedge and presented an equation for salt wedge length, L, for the weak mixture condition:

$$L=\frac{H(0.2F^{-2}-2+3F^{2/3}-1.2F^{4/3})}{2f_i} \tag{11}$$

where H: water depth average; F: density (inner) Froude number ($= u / (\varepsilon gH)^{1/2}$); u: the average of upper layer velocity; ε: ratio of density difference ($= \Delta\rho / \rho$); f_i: resistant coefficient of boundary layer.

Festa and Hansen (1976), as cited in Saijo and Okuda (1996), conducted numerical analysis of salinity and velocity distribution in the moderate mixture zones. They defined two-dimensional vertical cross sectional problems and simultaneously analyzed equation of motions and equations of advection and diffusion. In the analysis, they used two parameters:

Rayleigh number: $Ra=\beta g(\Delta S_h)H^3/(A_vK_v)$ (12)

Prandtl: $Pr=A_v/K_v$ (13)

where β: salinity density coefficient, $\rho=\rho_0 (1 + \beta S)$; ΔS_h: salinity difference between salt water in the river mouth and fresh water in the upper river; A_v: vertical eddy kinematic viscosity coefficient; K_v: vertical kinematic diffusion coefficient.

They illustrated some figures showing flow rate and salinity profiles for the longitudinal length of the rivers.

3 Some studies on salinity in the estuary estuarine zones of rivers

Gillibrand and Balls (1998) used a one-dimensional salt intrusion model to investigate the hydrography of the Ythan Estuary, Scotland, and found that the model successfully simulated salinity distribution for periods of high and low water. Wang et al. (2004) analyzed residence time of the Danshuei River Estuary, Taiwan, using a laterally integrated two-dimensional hydro-dynamic eutrophication model (HEM-2D) and found that relatively short residence time is likely to be one of the limiting factors that result in low phytoplankton biomass in spite of high nutrient concentrations. Liu et al. (2005) enhanced the model with a three-dimensional hydro-dynamic model and a water quality model based on the laterally integrated operation substances in the water column.

In regards to more complex estuary model including salinity, the Estuarine, Coastal, and Ocean Model (ECOM), which was used by Blumberg et al. (1999), was based on 1) meteorological data; 2) water level elevation and temperature and salinity fields along the open boundary; and 3) freshwater inflows from 30 rivers, 110 wastewater treatment plants, and 268 point sources from combined sewer overflows (CSO) and surface runoff. They conducted three-dimensional simulations of estuarine circulation in the New York Harbor complex, Long Island Sound, and the New York Bight within the framework of a single grid system. Suzuki and Matsuyama (2000) conducted numerical experiments using a three-dimensional model to explain the wind-induced circulation in Tokyo Bay. The results of the numerical experiments agreed qualitatively with data from both the sea-surface temperature obtained by satellite images and field measurements at moored stations in the bay.

4 Methods

4.1 Water quality, flow rate and tidal level data

Water quality and flow rate data were obtained from web-site of Funabashi City (2003), Chiba Prefecture, named Funabashi Environmental Map, Ordinary Environment. Every two-hour monitoring for 24 hours has been conducted twice a Japanese fiscal year, from April to March. These daily monitoring data were used for the analysis in this study. Tidal level data were obtained from the Japan Oceanography Data Center (JODC). Tidal data at Chiba Port collected by the Japan Coast Guard were used for the analysis.

4.2 Salinity contour

Salinity contours were illustrated for salinity of upper layer and bottom layer at Yachiyobashi Bridge, nearest to the river mouth of the Ebigawa River. There is a concurrent point about 930 m upstream of Yachiyobashi Bridge, where mainstream of the Ebigawa River and the Nagatsugawa River meet each other. The nearest monitoring points of each river upstream are Fujimibashi Bridge, about 250 m upstream of the concurrent point for Ebigawa River mainstream, and Shinbashi Bridge, about 100 m upstream (from Japanese fiscal year (JFY) 1976 to JFY 1991) and Funabashi Haim about 840 m upstream (from JFY 1992 up to current).

Contour lines for salinity of 0.5, 10 and 20 psu were developed using interpolation and extrapolation methods on the assumption of moderate mixture conditions.

5 Results and Discussions

Fig. 3 shows some examples of salinity and flow rate with contour lines of 0.5, 10 and 20 psu at Yachiyobashi Bridge monitoring point, and tidal level of Chiba Port in 24-hour monitoring.

Daily profiles of salinity in upper layer and bottom layer, flow rate, and tidal level on March 7th and 8th, 1984 were illustrated in Fig. 3 (a1). Salinity in upper layer fluctuated from 0.6 to 11.7 psu, and that in bottom layer changed from 0.7 to 26.4 psu. Flow rate of upper layer had its maximum value, 1.4 $m^3\ s^{-1}$, in the late morning and its minimum value, 0.3 $m^3\ s^{-1}$, in the early morning. Tidal level at Chiba Port changed in the range from 94 to 231 cm. Herath and Musiake (1994) and Musiake (2003) pointed out large contribution of anthropogenic wastewater to the flow rate of Ebigawa River reflecting life cycle of ordinary people: larger flow rate in the late morning and evening. During this monitoring period, large contribution of anthropogenic wastewater and influence of tidal level change were supposed to form a peak in the late morning and another peak from the evening to midnight. These fluctuations of anthropogenic water and tidal level might contribute to rather stable flow rate. In the midnight, anthropogenic water amount decreased gradually and tidal level increased after 1:00, therefore, salinity in Fig. 3 (a2) shows salt wedge around 5:00.

On May 30th-31st, 1984, the lowest tidal levels at 11:00 in the morning and at 23:00 at night, and highest tidal levels at 17:00 in the evening and 5:00 in the morning on 31st were observed (Fig. 3 (b1)). This tidal

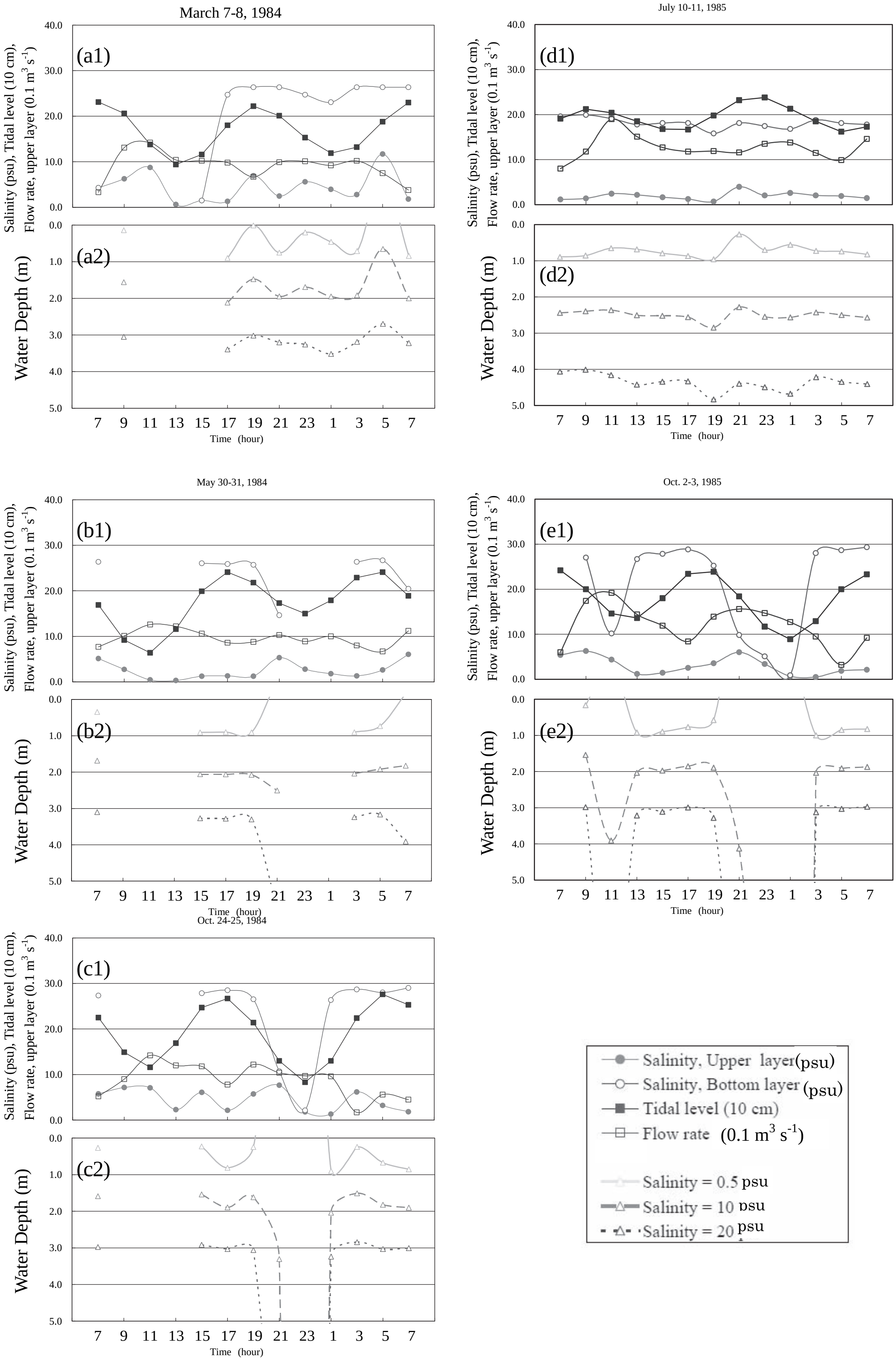

Fig. 3. Salinity, flow rate and tidal level fluctuations in 24-hour monitoring, and contour lines of 0.5, 10 and 20 psu. From (a1) to (e1) are measured data, and from (a2) to (e2) are calculated values.

level fluctuation and anthropogenic water influenced the flow rate: a peak in the morning on 30th, stable from the afternoon to midnight, and decrease in the early morning on the next day. Salinity in the bottom layer is supposed to be low in the morning (some data deficit), had a peak from 15:00 to 19:00, decreased from 21:00, and again had a peak from 3:00 to 5:00. Contour lines show this salinity profile also especially for high concentration period (Fig. 3 (b2)).

On Oct. 24th-25th, 1984, tidal level fluctuation was almost the same as that on May 30th-31st, except for low tide at 23:00, which was much lower than that on May 30th and might cause the relatively large flow rate at 19:00 and lower flow rate at 3:00 and 5:00 (Fig. 3 (c1)). Contour lines of 10 and 20 psu (Fig. 3 (c2)) were almost the same as those on May 30th-31st shown in Fig. 3 (b2).

On July 10th-11th, 1985, tidal range was relatively smaller than those on other days in the figure (Fig. 3 (d 1)). Anthropogenic water influence was supposed to influence much to flow rate, especially for a peak at 11:00. On the contrary, both anthropogenic water and tidal level fluctuation might cause a slight peak at 1:00. Contour lines were rather flat comparing to other four cases shown in Fig. 3, which showed weak mixture was observed on this day.

On Oct. 2nd-3rd, 1985, higher tides were observed at 7:00 and 19:00, and lower tides were observed at 13:00 and 1:00 (Fig. 3 (e1)). Decrease of tidal level and anthropogenic water were supposed to cause low salinity at the bottom layer and a peak of flow rate at 11:00 and another peak from 19:00 to 23:00. Contour lines (Fig. 3 (e2)) reflected the salinity fluctuation especially at the bottom layer shown in Fig. 3 (e1).

The daily profiles of salinity, flow rate, anthropogenic water and tidal level were summarized in Table 3. Profiles of anthropogenic water in the table were derived from Musiake (2003). In irrigation period, from May to July, agriculture use of groundwater and anthropogenic water including domestic wastewater contributed much to the flow rate of Ebigawa River, and anthropogenic water contributed much in non-irrigation period, from July to April (Musiake, 2003). In regards to the effect of tidal level fluctuation, tidal fluctuation supposed to cause increase of flow rate during the periods after high tide and before low tide. For the period after low tide and before high tide, flow from the river mouth to upstream increased and might cause decrease of fresh water flow. It might also possible that sea water flow upstream should cause increase of flow rate by increase of bottom layer flow rate to the upstream, and consequently might increase upper layer flow rate at certain point of the stream depending on the upper and lower layer conditions. Therefore, it is worth to investigate these data minutely even though qualitatively.

On March 7th-8th, 1984, shown in Table 3 (a), high peaks of tidal level were on 7:00, 19:00 and 7:00, high peaks of anthropogenic water were supposed around at 13:00 and 1:00. So, it was anticipated that flow rate increase and salinity decrease could be observed around the time of these peaks. The monitoring data showed that flow rate increase and salinity decrease were observed before 13:00 and highest flow rate was observed at 9:00 and 11:00, lowest salinity was observed at 13:00 to 17:00 for the upper layer and at 15:00 for the bottom layer. However, flow rate increase and salinity decrease were not observed around 1:00.

On May 30th-31st, 1984, Table 3 (b), times for lowest tidal level and highest anthropogenic water were coincident, 11:00 and 23:00, when large flow rate and large salinity were anticipated. Flow rate had a peak around 11:00. Around 23:00, flow rate was rather flat or salinity decreased judging from contour lines (Fig. 3 (b 2)) and contour line pattern at 21:00 was “2”, which means that contour line of 10 psu was above 5.0 m and 20 psu was below 5.0 m.

On Oct. 24th-25th, 1984, Table 3 (c), times of lowest tidal level were 11:00 and 23:00. Times of largest anthropogenic water were 13:00 and 1:00. The largest flow rate was recorded at 11:00, which might be expected as the effects of lowest tidal level at 11:00 and large anthropogenic water at 13:00. Salinity in the upper layer was largest at 11:00. Fresh water increased around 21:00 and 23:00, and salinity of the bottom layer was lower because of low and large anthropogenic water.

On July 10th-11th, 1985, Table 3 (d), times of lowest tidal level were 17:00 and 5:00. Anthropogenic water was largest at 11:00 and 23:00. Precipitation was recorded for three hours in the morning, July 11th, from 5:00 to 7:00 for each 2 mm/hour, which might cause increase of flow rate. However, Fig. 3 (b) and (e) also show similar increase of flow rate in the morning without precipitation. So, further consideration is necessary for the relationship between precipitation and flow rate. Flow rate was highest at 11:00, when anthropogenic water was high, and tidal level changed from highest to lowest during the period. Flow rate was smallest at 21:00, in the time of tidal level changed from lowest to highest. On the monitoring day, two-layer of salinity was rather clearly observed comparing to other monitored days in Fig. 3. It was observed that weak mixture was formed in these days. Therefore, from 17:00 to 23:00, lowest tide to highest tide, it was expected that upper flow from the river mouth to upstream in the bottom layer existed. Relatively high salinity was observed at 21:00, which might expected some portions of salt water in the bottom layer should enter in to the upper layer. At this time, 21:00, flow rate was lowest, which are considered to be rather quantitatively complicated

Table 3. Profiles of tidal level, anthropogenic water, flow rate, salinity and contour lines of salinity for 24-hour monitoring at Yachiyobashi Bridge, Ebigawa River, Chiba Prefecture.

(a) March 7th-8th, 1984

Time	7		9		11		13		15		17		19		21		23		1		3		5		7
Tidal level[a]	H	-		-		-	L	+		+		+	H	-		-		-	L	+		+		+	H
Anthropogenic water[b]		-	L	+		+	H	-		-	L	+		+		+		+	H	-		-		-	
Flow rate[c]	(L)	+	H		H	-						-		+								-		-	(L)
Salinity, upper layer[d]		+		+	H	-	L		L		L	+										+	H	-	
Salinity, bottom layer[d]									L	+	H		H		H		H		H		H		H		H
Contour line pattern[e]	3										3		3		3		3		3		3		3		3

(b) May 30th-31st, 1984

Time	7		9		11		13		15		17		19		21		23		1		3		5		7
Tidal level[a]	H	-		-	L	+		+		+	H	-		-		-	L	+		+		+	H	-	
Anthropogenic water[b]	L	+		+	H	-		-		-	L	+		+		+	H	-		-		-		-	
Flow rate[c]		+		+	H		H	-		-				+		-		+		-		-	L	+	
Salinity, upper layer[d]		-		-	L		L		L		L		L	+	H	-		-		-	L	+		+	
Salinity, bottom layer[d]								+	H		H		H	-							H		H	-	
Contour line pattern[e]	3						1		3		3		3		2						3		3		3

(c) Oct 24th-25th, 1984

Time	7		9		11		13		15		17		19		21		23		1		3		5		7
Tidal level[a]	H	-		-	L	+		+		+	H	-		-		-	L	+		+		+	H	-	
Anthropogenic water[b]		-	L	+		+	H	-		-	L	+		+		+		+	H	-		-		-	
Flow rate[c]		+		+	H	-				-	L	+		-						-	L	+		-	
Salinity, upper layer[d]		+		+	H	-	L	+	H	-	L	+		+	H	-		-	L	+	H	-		-	
Salinity, bottom layer[d]									H		H		H	-		-	L	+	H		H		H		H
Contour line pattern[e]	3								3		3		3	-	2		1		3		3		3		3

(d) July 10th-11th, 1985

Time	7		9		11		13		15		17		19		21		23		1		3		5		7
Tidal level[a]		+	H	-		-		-			L	+		+		+	H	-		-		-	L	+	
Anthropogenic water[b]	L	+		+	H	-		-		-	L	+		+		+	H	-		-		-		-	
Flow rate[c]		+		+	H	-		-		-					L	+		+	H	-		-	L	+	
Salinity, upper layer[d]														+	H	-									
Salinity, bottom layer[d]				-		-						-	L	+	H	-		-		+	H	-		-	
Contour line pattern[e]	3		3		3		3		3		3		3		3		3		3		3		3		3

(e) Oct 2nd-3rd, 1985

Time	7		9		11		13		15		17		19		21		23		1		3		5		7
Tidal level[a]	H	-		-		-	L	+		+	H		H	-		-		-	L	+		+		+	H
Anthropogenic water[b]		-	L	+		+	H	-		-	L	+		+		+		+	H	-		-		-	
Flow rate[c]		+		+	H	-		-		-	L	+		+	H	-		-		-		-	L	+	
Salinity, upper layer[d]		+	H	-		-	L	+		+		+		+	H	-		-	L		L	+			
Salinity, bottom layer[d]		+	H	-	L	+	H		H		H		H	-		-		-	L	+	H		H		H
Contour line pattern[e]			3		2		3		3		3		3		3		2		1		1		3		3

a) H: high tide, L: low tide, -: tidal level decrease, +: tidal level increase;

b) Fluctuation patern of anthropogenic water flow rate was derived from Musiake (2003);

c) H: high peak, L: bottom peak, -: decrease, +: increase; (parentheses): end point time in the monitoring period and H or L was supposed from the available data;

d) H: high peak, L: bottom peak, -: decrease, +: increase;

e) 1: both contour lines of 10 and 20 psu are below 5.0 m, 2: contour line of 10 psu is above 5.0 m and 20 psu is below 5.0 m, 3: both contour lines are above 5.0 m.

observation. Another highest flow rate was observed at 1:00, which might be the results of the large anthropogenic water contribution and tidal level change from the highest to the lowest level.

On Oct 2nd-3rd, 1985, Table 3 (e), lowest tidal level and high peak of anthropogenic water observed at the same time at 13:00 and 1:00, which were the same as shown in Table 3 (a) and (b), March 7-8, 1984, and May 30th-31st, 1984, and similar to Table 3 (c), Oct 24th-25 th, 1985. Large flow rate at 11:00 was coincidence with tidal level and anthropogenic water, however, another large flow rate at 21:00 was rather not coincidence with these two reasons, anthropogenic water and tidal level. Contour line pattern was "2" at 11:00 in the morning, and at the midnight, "2" at 23:00 and "1" at 1:00 to 3:00, fresh water increased in these times, which might be the results of the tidal level fluctuation and anthropogenic water.

Contour lines analyses shown in Fig. 3, and defining contour line patterns in Table 3 including anthropogenic water effects as a qualitative parameter, could enhance understanding of the flow and salinity patterns in the estuarine zone of a river.

These tendencies of the parameters of the monitored water quality and quantity data could be quantitatively studied in the further research. Some hydrodynamic/hydrologic models are to be established to figure out the flow rate and water quality profiles in the future works.

Supplement data for other monitoring periods, which are not described in the paper are to be available on homepage of ReCCLE, Shimane University.

6 Conclusion

As a preliminary study to illustrate water quality and quantity profiles in the estuarine zones of inner-city rivers, salinity, tidal level and flow rate were summarized for the Ebigawa River, Funabashi City, Chiba Prefecture, by use of public water monitoring data. Contour lines analyses, including anthropogenic water effects as a qualitative parameter, and defining contour line patterns could enhance the understanding of the flow and salinity patterns in the estuarine zone of a river. It was qualitatively assured that tidal level fluctuations and anthropogenic water, water related to human activities, are two main reasons of the flow rate of the estuarine zone and its salinity in the river.

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