Water Quality Behavior in the Kiso River Tidal Embayment

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Abstract: It is known that the tidal flat in an estuary has natural water-purification function through the biochemical action such as denitrification, feeding bivalves, etc. Purpose of this study is to evaluate water quality change in an embayment influence that of a tidal river. For the purpose, we investigated the water-purification ability of the sand bar and the embayment in the Kiso river tidal area as an inlet of the Ise bay. In the Kiso river tidal area, a series of groins was constructed in the Meiji Era, sand bars and embayments have been formed around groins.

We performed the field observation focusing on the water quality at the embayment in 18.8km point. The time dependent change of the concentration of the chloride ion was observed. This clarified that horizontal flow of the surface water in the embayment has periodical change regulated mainly by the tide. It was also clarified that the concentration of nitrate-nitrogen in the subsurface water leached from sediment at the low tide was lower than that of the main channel, and we estimated that this difference is caused by the biochemical action inside of sediment. We estimated water and material budget between the main channel and the embayment using horizontal two-dimensional flow and material transport analysis. As a result, we estimated the total reduction of the contained nitrate-nitrogen in the section, and it confirmed that the water-purification ability caused by the presence of the sedimentary area is estimated.

Keywords: Nutrient, Tidal River, Groin, Embayment, Kiso River

1. INTRODUCTION

Hyper-eutrophic environment in an enclosed bay causes generation of red tide, which causes extensive damage to fishery. Nutrient load through the river is one of the critical factors to produce and develop the hyper-eutrophic environment. Thus, the reduction of nutrient load is quite important matter to suppress the development of the eutrophic environment. In particular, it is known that the tidal flat in an estuary has natural water-purification function through the biochemical action such as denitrification, feeding bivalves, etc. In this study, we investigated the water-purification ability of the sand bar and the embayment in the Kiso river tidal area as an inlet of the Ise bay. In the Kiso river tidal area, a series of groins was constructed in the Meiji Era, sand bars and embayments have been formed around groins. In the embayments, Kimura et al. [1] investigated with regard to the morphological evolution, environmental functions. Takeda et al. [2] showed temporal change of water temperature in the embayment due to tide using field observation and numerical analysis. However, behavior of water quality in particular nutrients is not clarified. Purpose of this study is to evaluate water quality change in an embayment influence that of a tidal river.

We performed the field observation focusing on the water quality behavior at the embayment in 18.8km point. The time dependent change of the distribution of the chloride ion (CT) was observed. This clarified that horizontal flow of the surface water in the embayment has periodical change regulated mainly by the tide. It was also clarified that the concentration of nitrate-nitrogen (NO₃⁻N) in the subsurface water leached from sediment at the low tide was lower than that of the main channel, and we estimated that this difference is caused by the biochemical action inside of sediment. We carried out the horizontal two-dimensional flow and material transport analysis. We estimated water and material budget between the main channel and the embayment. As a result, we estimated the total reduction of the contained NO₃⁻N in the section, and it confirmed that the water-purification ability caused by the presence of the sedimentary area is estimated.
Iw

5,275 km². The observation area is located at the tidal length of the river is 229 km, and the catchment area is in Nagoya, Japan, during 14 and 15 October of 2005. The field observation was performed in the Kiso River.

2. FIELD OBSERVATION

2.1. Observation Area and Period

The field observation was performed in the Kiso River in Nagoya, Japan, during 14 and 15 October of 2005. The length of the river is 229 km, and the catchment area is 5,275 km². The observation area is located at the tidal reach of the river (26 km upstream from the river mouth) which shown in Fig. 1. In the region, a series of groins was constructed in the Meiji Era, sand bars and embayments have been formed around the groins. We observed one of the embayments which is located at the 18.8 km point. Fig. 2 is shown water level (W.L.) in the Katsuragi station (18.3 km point) is the same W.L in the study site [3] and W.L. gradient near the site at the observing. The W.L. gradient between the Katsuragi and the Owada station (in 22.7 km point) is defined as Iw. When Iw is a reverse gradient, the backflow would be formed from the river mouth with salinity intrusion.

The sand bar surface of the study site is covered with impermeable silt which reach a thickness of 10 cm. Therefore, it is suggested that the exchange between surface water and subsurface water in the sand bar is done through the two creeks (the secondary channels) which is not covered with silt and exposed the sand layer in river bed of the two creeks. Only the surrounding of these creeks is flooded at high water level, and the whole of the sand bar is not flooded. Sumi et al. [3] and Tsujimoto et al. [4] indicated the creek oozes from sand layer with delay at the low tide, since the water level of the creek is higher than that of the main channel. Therefore, the creek water is formed subsurface water at the low tide.

2.2. Methods of Field Observation

Fig. 3 shows the observed points. In Fig. 3, station (st.) MU and MD are located at edge of the groin in the upstream side and downstream side, respectively. Measurements were performed seven times every three hours (Fig. 2). Methods of field observation are measurements of water quality and water sampling. Water quality (Temperature, pH, etc.) and depth were measured using a multiple water quality meter (Toa DKK, WQC-24). Water samples were taken at a water surface. The samples were brought to laboratory, then later these were analyzed contained ion (Cl⁻, NO₃-N, etc.) using ion analyzer (Toa DKK, IA-200), and only PO₄-P was analyzed using molybdenum blue colorimetric method.

The reason for measuring Cl⁻ is to understand the flow pattern by using the characteristics of Cl⁻ as a conservative substance. It is disregarded here because the observed value in the Tokai bridge of the main channel upstream (in 22.6 km point) was a small value of about 0.01mg/L for NH₄-N (ammonium-nitrogen) and NO₂-N (nitrite-nitrogen). It is impossible to detect them from the samples.

2.3. Results and Discussion

Fig. 4 shows distribution of Cl⁻ and NO₃-N concentrations. As a Cl⁻ is not varied due to biochemical reaction, the distribution of Cl⁻ shows characteristics of mass transfer. At the falling tide and ebb tide, Cl⁻ was transported to the main channel from the embayment. At the rising tide, Cl⁻ concentration in the embayment was lower than that at the falling tide. However, Cl⁻ concentration in the st. MD was higher than st. MU for the salinity intrusion. Moreover at the high tide, the value of Cl⁻ is 100 mg/L at the st. MD was higher than that of freshwater value was 7 mg/L. In addition, high value Cl⁻ contained water reach near the levee in the embayment. The cause for the variation of the Cl⁻ concentration at any time was not considered bottom water flow for the water sampling at the surface water only.

The distribution of NO₃-N was similar to the Cl⁻ concentration. However, at the falling tide toward the rising tide, NO₃-N concentration near the levee in the embayment (st. 0, L, and R) was lower than that of main channel (st. MU and MD). In particular, st. L and R are located at the creek. As the above mentioned, the creek water is formed subsurface water (viz. leachate). Therefore, it is suggested that the creek water is affected biochemical action such as denitrification inside the sand bar.
3. NUMERICAL ANALYSIS

3.1. Methods of Numerical Analysis

Numerical analysis was performed to figure out the water quality behavior. Numerical analysis is formed horizontal two dimensional (H2D) flow model and H2D material transport model. H2D flow analysis is based on the continuity equation and the Reynolds equations as follows:

\[
\frac{\partial h}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0
\]  

\[
\frac{\partial M}{\partial t} + \frac{\partial M u}{\partial x} + \frac{\partial M v}{\partial y} = -gh \frac{\partial (h + z_c)}{\partial x} \\
+ \frac{\partial}{\partial x} \left[ h \left( 2v + \frac{\partial u}{\partial x} - \frac{2}{3} k \right) \right] \\
+ \frac{\partial}{\partial y} \left[ h v \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right] - g n^2 \sqrt{u^2 + v^2} \frac{h^{5/3}}{h^{5/3}}
\]  

Fig. 4. The distribution of Cl$^-$ and NO$_3$-N concentrations
where \( t \): time, \((x, y)\): Cartesian coordinates (flow and width direction), \( h \): depth, \((u, v)\): flow velocity (x and y direction), \((M, N)\): discharge flux \((M=uh, N=vh)\), \( g \): gravitational acceleration, \( z_b \): river bed elevation, \( n \): Manning’s coefficient, \( v \): coefficient of eddy kinematic viscosity \((=\alpha u h, \alpha =0.3)\), \( u^* \): shear velocity, \( k \): turbulent viscosity \((=2.07 u^* h)\).

H2D material transport analysis is based on the advection-diffusion equation as follows:

\[
\frac{\partial C}{\partial t} + \frac{\partial (CM)}{\partial x} + \frac{\partial (CN)}{\partial y} = \frac{\partial}{\partial x}\left( hK_x \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y}\left( hK_y \frac{\partial C}{\partial y} \right) + hS
\]  

where, \( C \): material concentration, \((K_x, K_y)\): turbulent diffusion coefficient, \( S \): exchange flux.

For simplifying the embayment, computational grid was square grid which scale was \( \Delta x = 20 \) m and \( \Delta y = 20 \) m. The governing equations were discretized by finite volume method on the staggered grid system. Temporal differences were approximated by the leap-frog scheme. The Donor scheme was used for the advection terms, and the second order center difference was employed for the other spatial derivatives.

For the boundary conditions the flow discharge and the concentrations of \( Cl^- \) = 7 mg/L and \( NO_3-N \) = 0.4 mg/L were provided at the upstream end of the computational domain. The fraction of flow discharge \((Q = 120 \) m\(^3\)/s, constant.) in each grid at the upstream end was determined in proportion to \( h^{10} \) in accordance with Manning’s law. Water level of sine wave at amplitude is 1.0 m was provided at the downstream end. The initial condition of \( Cl^- \) and \( NO_3-N \) is 100 mg/L and 0.3 mg/L, respectively.

### 3.2 Results and Discussion

Fig. 5. shows the ratio of exchange volume between the main channel and the embayment to the main channel inlet volume. The ratio about water volume at the rising tide condition was higher than the low tide condition. It is suggested that at the rising tide affected by the upstream inlet flow such as shear mixing and transverse flow toward the embayment from the main channel due to tidal motion. Therefore, if in the main channel arise a backflow, water quality behavior inside the embayment influence water quality of sea water.

### 4. CONCLUSION

As result of the field observation, it is clarified that material exchange between the main channel and the embayment is occurred due to tide. In particular, it is suggested that \( NO_3-N \) concentration inside of the sand bar is reduced due to biochemical action such as denitrification. It is not only the result of field observation, but also the result of numerical analysis is shown material exchange between the main channel and the embayment due to shear mixing and tidal motion.

### REFERENCES