Effect of large-scale flooding on water quality of Tokyo bay

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ABSTRACT: Tokyo Bay is a well-known eutrophic inner bay in Japan, and the subsurface hypoxia in Tokyo Bay has frequently been found during the summer months. Although the appreciable pollutant load has significantly influenced the issues with the water quality in Tokyo Bay, there has been very little information on the influences of the non-point sources due to flooding on the water quality in Tokyo Bay. To clarify what the influences of large-scale flooding are on the water quality of the Bay, we performed field measurements on the pollutant loads under flood conditions using automatic water samplers. We also evaluated the long-term trends of the pollutant loads, and investigated their relation with the water quality in the benthic layer of Tokyo Bay.

The results indicated that large-scale flooding caused by the impact of typhoon no. 0709 was a significantly huge environmental event in Tokyo Bay. The comparison between the pollutant loads and DO in Tokyo Bay indicated that the subsurface hypoxia developed in the head of the bay after the large-scale flooding was mainly due to the decomposition of organic materials appreciably transported in the influent rivers.

1 INTRODUCTION

During the high flow conditions in rivers, a large amount of freshwater, sediment, nutrients and organic materials are generally transported from inland to receiving water like that in the coastal regions (*e.g.*, Tappin, 2002). These flood events may therefore have a huge environmental impact on the coastal environments (Eyre & Balls, 1999). The appropriate management of the water-quality environments in eutrophicated semi-enclosed bays needs to clarify the pollutant loads under high-flow conditions, and the response of the water quality in semi-enclosed bays.

The pollutant loads, which are a concentration of the subject of materials times the river discharge, must always be known. Although the discharge is typically monitored using a rating curve between the continuously measured water stage and the discharge, the pollutant concentration is typically measured only periodically (*e.g.*, weekly or monthly) under low-flow conditions. To evaluate continuous pollutant loads, a rating curve between the sporadically-observed pollutant loads and the discharge has generally been used in most previous studies and regulatory agencies (Tappin, 2002). However, the rating curve for pollutant loads has difficulty in estimating accurate fluxes (Phillips et al., 1999; Horowitz et al., 2001; Stubblefield et al., 2007; Shivers & Moglen, 2008), since there is little data concerning the pollutant loads under high-flow conditions due to their infrequent nature and difficulties in being accurately measured. Furthermore, the environmental impacts from inland to the coast during large-scale flooding are still unclear.

The most crucial points concerning the above-mentioned issues is the collection of field data of the riverine loads during large-scale flooding. For this purpose, in the present study, field measurements of the pollutant loads under flood conditions were performed using automatic water samplers in the various types of rivers flowing into Tokyo Bay, in which eutrophication

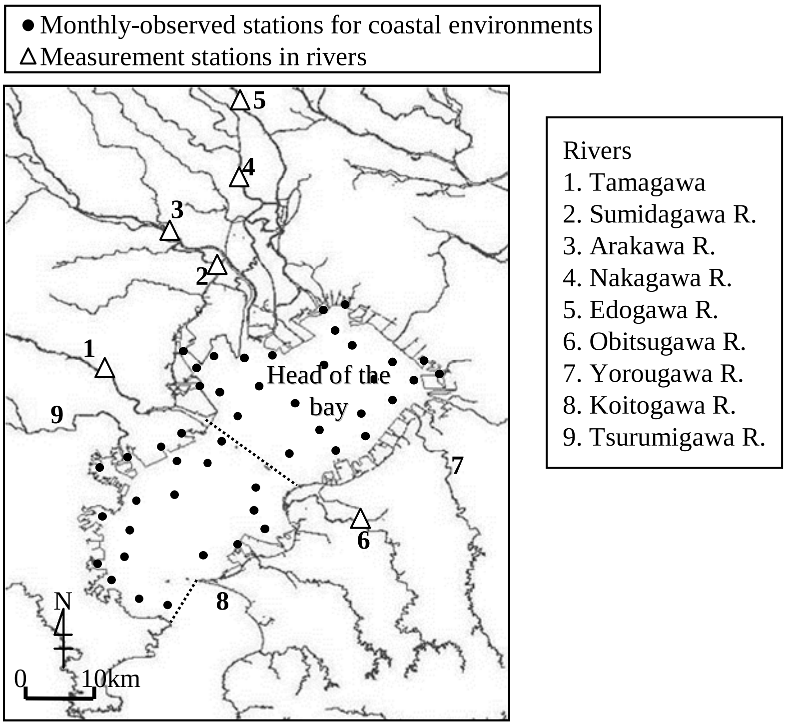

Figure 1. Measurement stations in rivers and data-analysis points for water quality in Tokyo Bay.

has appeared over a few decades and in which the subsurface hypoxia was frequently observed during the summer months. In addition, we evaluated the annual pollutant loads of the SS, organic materials, and nutrients, and investigated its relation with the DO and nutrients in the benthic layer of Tokyo Bay. From these data analysis, we try to clarify the influences of large-scale flooding on the water quality of Tokyo Bay.

2 METHODS

2.1 *Study area*

Tokyo Bay is one of the most important estuaries in Japan and is located at the center of Japan. The surface area and mean water depth of Tokyo Bay are 1000 km^2 and about 17 m, respectively. Its watershed includes Tokyo, Kanagawa, Chiba, and Saitama Prefectures, which covers an area of about 7000 km^2. A large amount of human pollution from the watershed is discharged into Tokyo Bay mainly through nine large rivers, as shown in Fig.1, and therefore, have caused the eutrophication in Tokyo Bay.

2.2 *Field measurements of pollutant loads in rivers*

We performed field measurements of the pollutant loads in the main rivers flowing into Tokyo Bay under flood conditions. The field sites chosen in the present study are the Edogawa, Arakawa, Tamagawa, Nakagawa, Sumidagawa and Obitsugawa Rivers, which are the main influent rivers into Tokyo Bay. At the measurement stations shown by the triangles in **Fig. 1**, we mounted automatic water samplers that can automatically collect river water at any time including during flood events. A total of twelve flood events were sampled between June 2006 to September 2008. The observed flooding includes that caused by typhoon no. 0709, which recorded the biggest discharge over the last 25 years in the Tamagawa and Arakawa Rivers. The collected water samples were analyzed for TSS (total suspended solids), VSS (volatile suspended solids), COD, T-N (total nitrogen) and T-P (total phosphorus).

To evaluate the pollutant loads over a long period of time, rating curves for the sediments, nutrients, and COD were developed by using a least-square regression expressed as

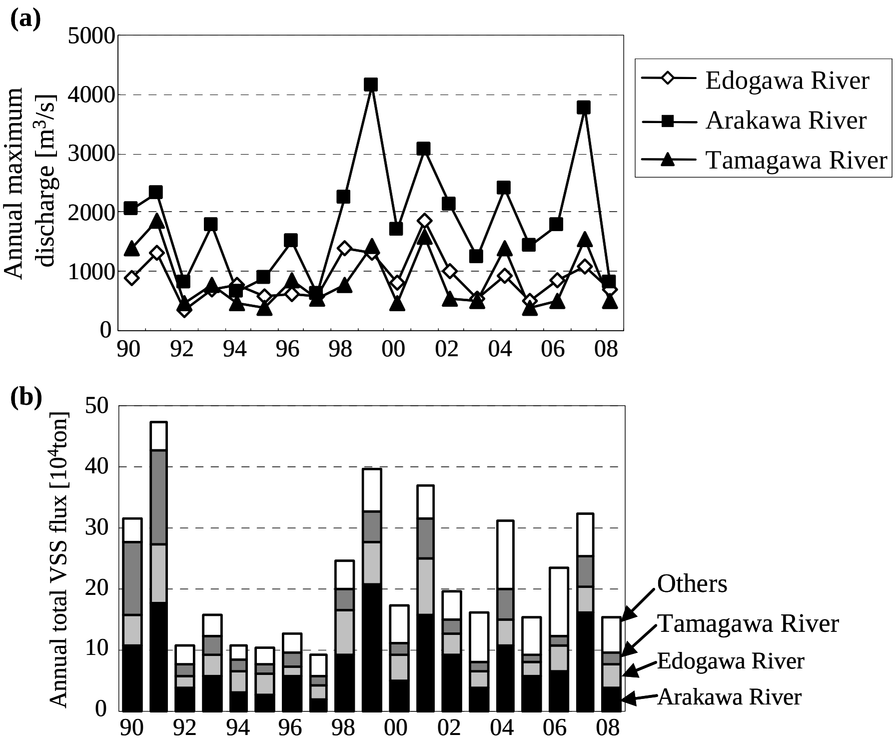

Figure 2. Long-term trend of (a) annual maximum discharge and (b) annual total VSS flux.

$$L = aQ^b , \tag{1}$$

where Q is the discharge, L is the pollutant load, and a and b are the constant and exponent of the rating curves. The regression analysis for each pollutant in each river was performed using the pollutant loads observed under flood conditions. The Tsurumigawa, Yorougawa, and Koitogawa Rivers were not chosen as field sites for this study. Since the land use of the watershed in the Tsurumigawa River is similar to that in the Nakagawa River, the values of a and b obtained in the Nakagawa River were applied to those for the Tsurumigawa River. In the same way, the a and b values used for the Obitsugawa River were used for the Yorougawa and Koitogawa Rivers. The rating curve for the pollutants is used only for the high-flow conditions while the monthly-observed water quality in each river taken by the local governments is used to estimate the loads during low-flow conditions.

2.3 *Data analysis for water quality in inner bay*

The water-quality database observed monthly by the local governments was analyzed to evaluate the influences of the flood impact on the water quality in Tokyo Bay. Figure 1 shows the measurement stations for the water quality. The numbers for these stations are 26 and 21 in the head and mouth of the bay, respectively. The water qualities in the surface and bottom layers were measured at each station. The water temperature, salinity, COD, T-N, T-P, and DO observed from 1998 to 2007 were also used in this study.

3 RESULTS AND DISCUSSION

3.1 Long-term trend of pollutant load

Figure 2 illustrates the pollutant flows under large-scale flood conditions into Tokyo Bay and indicates the long-term trend of the annual total VSS fluxes in the Arakawa, Edogawa, and Tamagawa Rivers in which the sediment transports are dominant among the influent rivers into Tokyo Bay. The summation of the VSS fluxes in the other six rivers is also depicted in this fig-

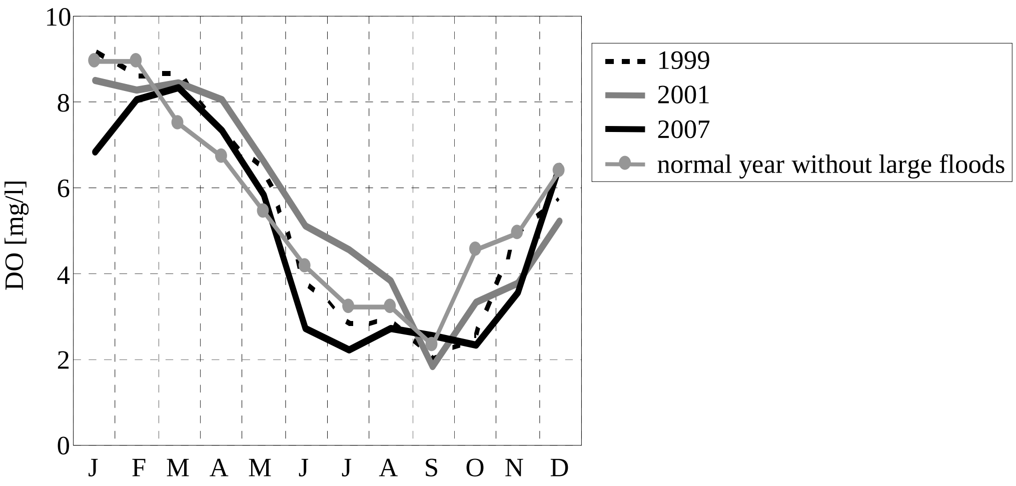

Figure 3. Monthly variations of DO in benthic layer of the head of bay in years with large-scale floods (1999, 2001, and 2007) and normal years without large floods.

ure. The annual maximum discharges in the main three rivers to check the magnitude of annual flood are shown in Fig. 2 (a). The results indicate that the annual total VSS fluxes were dominant in 1999, 2001, and 2007 in which large-scale flooding occurred. The dominant VSS fluxes in 1991, 1998, and 2004 were also observed because more than two floods with the magnitude of an average annual flood occurred. The summation of the VSS fluxes in the Arakawa, Edogawa, and Tamagawa Rivers were 50–90 % of those of all rivers.

Next, we focused on the total transported pollutants during a flood event using the temporal variations of the VSS fluxes in all rivers evaluated during this study. During the large-scale flood resulting from typhoon no. 0709 (from 5 to 11 September in 2007), the total of 76000 tons of transported VSS corresponding to two-fifth of that in the normal year was recorded. A huge amount of T-N, T-P, and COD were similarly transported during this hydrologic event. These results reveal that a large amount of pollutants were exported into Tokyo Bay during an appreciably short duration.

3.2 *Variation of DO in Tokyo Bay in large-scale floods*

To extract the influences of the huge impact of large-scale floods on the DO in Tokyo Bay, monthly variations of the bottom DO, averaged in the head of the bay, in the years with large-scale flooding are shown in Fig. 3. As mentioned above, these were for the large-scale floods that occurred in 1999, 2001, and 2007. For comparison, the variations of the DO in the normal years without large-scale flooding are also depicted in the figure. The results in the normal years indicate that the subsurface hypoxia was found during the summer and dissolved in October. In contrast, in the years with large-scale flooding, minimum values of DO appeared in the months when the floods occurred or in the following month. In addition, the DO during autumn in the years with large-scale flooding was significantly lower than that in a normal year. This fact indicates that subsurface hypoxia may appear over a longer period in years with large-scale flooding.

To check the relation between the subsurface DO and stratification, Fig. 4 reveals the correlation between the DO in the benthic layer and the vertical difference in the water temperature ΔT ($= T_s - T_b$, T_s, and T_b are the water temperatures in the surface and bottom layers) in the years with and without large-scale flooding. The values of DO and water temperature in the figure were averaged for those in the head of the bay. Although the clockwise loop is commonly observed for the correlation in the years with and without large-scale flooding, the loops in the years with large-scale flooding were larger than that in the normal years. This result means that, in the years with large-scale flooding, low DO values were maintained during the few months just after the stratification was destroyed. The subsurface hypoxia under no stratification may be

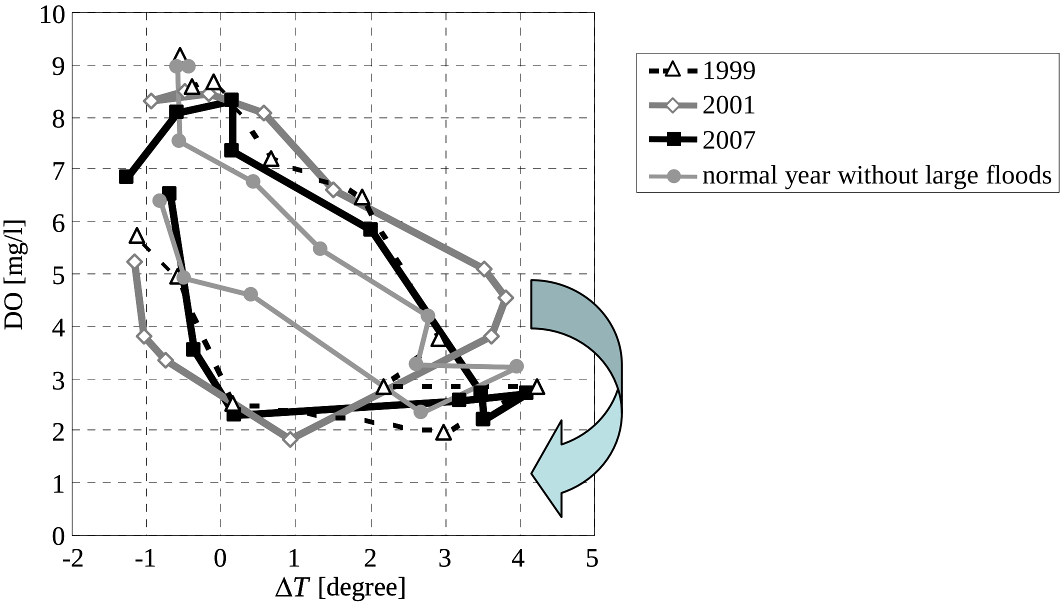

Figure 4. Correlation between benthic DO and vertical difference of water temperature ΔT in years with and without large-scale flooding.

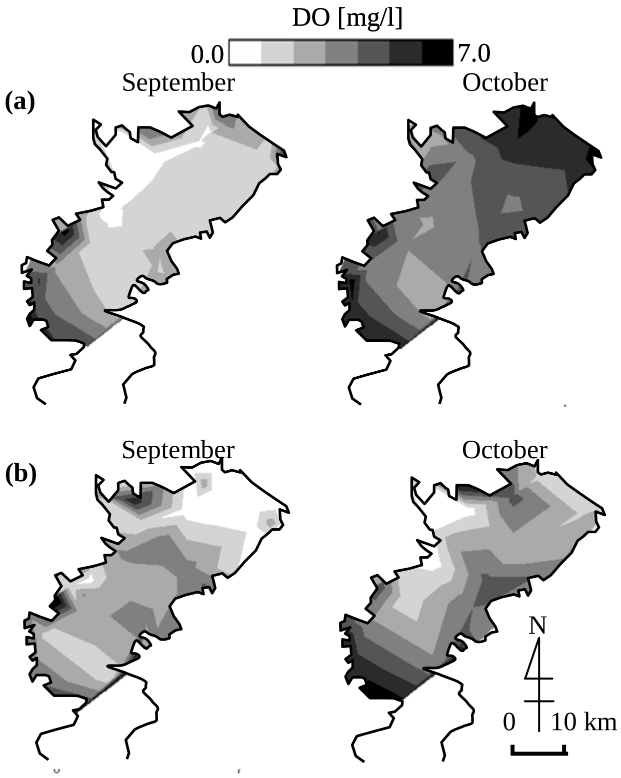

Figure 5. Contours of benthic DO in September and October in normal year (a) and in 2007 with large-scale flooding (b).

caused by a large DO consumption in which the source is a large amount of organic carbon supplied by large-scale flooding from inland.

Figure 5 indicates the contour maps of the benthic DO in September and October in 2007 in which large-scale flooding due to typhoon no.0709 occurred in September. For comparison, the spatial map of the benthic DO for a normal year is also depicted in the figure. In a normal year, a benthic hypoxia with a DO of under 2 mg/l was found over the entire bay during September and it was almost dissolved during October. On the other hand, in 2007, the benthic hypoxia was distributed around the head of the bay during September. In October 2007, the benthic hypoxia was kept around the western side of the head, which is near the mouth of the Arakawa and Tamagawa Rivers. Since most of the organic materials transported through the rivers under flood conditions was deposited near the river mouths, the DO consumption of the deposited organic materials may cause and maintain the benthic hypoxia in the head of the bay.

4 CONCLUSION

We performed field measurements on the pollutant loads under flooding conditions, evaluated the long-term trends of the pollutant loads, and investigated its relation with the water quality in the benthic layer of Tokyo Bay in this study to clarify the influences of large-scale floods on the water quality of Tokyo Bay. The results for the pollutant loads indicated that a large amount of pollutants are exported into Tokyo Bay during an appreciably short duration due to large-scale flooding. In a normal year, subsurface hypoxia was found during the summer months and was dissolved in October. In contrast, in the years with large-scale flooding, minimum values of DO appeared in the months when floods occurred or in the following month. Then, the DO during autumn in the years with large-scale flooding was significantly lower than that in a normal year. This fact indicates that subsurface hypoxia may appear over a longer period in the years with large-scale flooding. The comparison between the pollutant loads and DO in Tokyo Bay indicates that subsurface hypoxia at the head of the bay was accumulated after large–scale flooding mainly due to the decomposition of organic materials appreciably transported through the influent rivers. It should be also noted that monthly-collected data used in this study may well have missed some key peaks for water-quality variations. We should check the above conclusion using continuously monitored data in future work.

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