Simulation of the Probability of Occurrence of Oxygen-Deficient Water in the Shallow Zones of Hakata Bay, Japan

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1. Introduction

Eutrophication and the associated occurrence of oxygen-depleted bottom waters is one of the growing problems in the coastal bays due to excessive input of nutrients and organic materials from urban and industrial establishments. The number of species and abundance of benthic organisms and fishes are strongly associated with the dissolved oxygen in the near bottom water. When DO will be less 3.6 mg/L, the normal distribution of benthos begins to change and initiates the mortality of yellowtail tuna and almost all species of fish are influenced. Benthic infunal and shellfish mortality will be initiated when DO drops below 2 mg/L. Water having DO in between 0.036 mg/L to 3.6 mg/L is termed as oxygen-deficient water mass and DO of 0.036 mg/L is the upper limit of anoxic water [1)].

Although the tolerance of aquatic life to oxygen-depletion is well known, evaluation of the probable spatial and temporal damage and severity associated with oxygen-depleted water on ecosystem is still remained difficult. However, this is related with the occurrence probability of oxygen-depleted water. Since the physical and biological processes controlling DO dynamics in the ecosystem are inherently random, probabilistic calculation of the occurrence of oxygen-depleted water are more realistic and informative, which represent an indirect measure of the probable spatial and temporal damage and severity in the ecosystem. If the occurrence probability of in a particular time interval is high, its subsequent adverse effects and severity on the ecosystem will also be high. This paper presents a methodology of calculating the probability of occurrence of oxygen-depleted water within a combined hydrothermal and eutrophication model for the case in the shallow water zones of Hakata Bay (Fig.1). Since the meteorology has a significant influence on the formation of oxygen-deficit water, so long-term simulations for 20 years from 1980 to 1999 were also carried out to examine the influence of meteorology on formation and progressive development of oxygen-depleted water and the succeeding probability of occurrence and duration of this event. The inner Hakata Bay has been suffering from eutrophication and onset of hypoxic and anoxic conditions at the bottom water in every summer due to excessive organic and nutrients loadings from Fukuoka City and its catchment.

2. Methodology

DO of less than 3.6 mg/L was considered as the oxygen-depleted water and the probability of its occurrence, P within every 10 days at bottom water was defined as:

$$P = \frac{N_{odw}}{N_T} \qquad (1)$$

in which, N_{odw} is the number of occurrence of oxygen-depletion event in a computational time interval of 30 min within 10 days and N_T = 10 days/30 min = 480. In order to simulate the DO dynamics of the bay, a 3-D combined hydrothermal and eutrophication model (CHEM) was used The hydrothermal model is the extension of the multi-level stratified flow model MK2 [2)] by including a heat transfer sub-module and the eutrophication model is an integrated model of material circulation between water column and bottom sediment, which incorporated nine state variables such as organic and inorganic phosphorus, organic, ammonia and nitrates nitrogen, COD and DO and two biological components, phytoplankton and zooplankton.

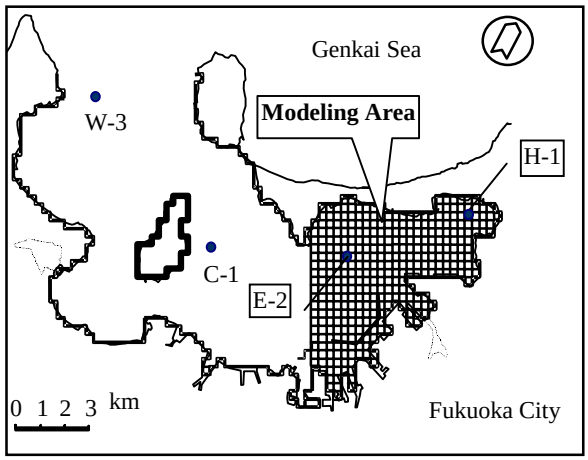

Fig.1 Hakata Bay, modeling area, water quality monitoring stations and model grid.

3. Results and Discussions

Contours of the probability of occurrence and progressive development of oxygen-depleted bottom water are shown in Fig. 2. These contours are the averaged results of our simulations under a wide range of meteorology from 1980 to 1999, thus give the representative average of the general trends and the most probable occurrence of oxygen-depleted condition of the bay in a year. Oxygen-depleted bottom water first appears at the end of June, and then gradually expanded and is most severe during August, when a larger part of the bottom water is experienced by oxygen-depleted condition with high probability of occurrence. These contours also point out the probable damage and severity associated with bottom oxygen-depletion on ecology including mortality of fishes and benthic community and it is most intense in this period in the bay. By the end of September, oxygen-depleted water gradually disappears by the onset of cooling and subsequent breakdown in the strength of water column stratification. Water temperature in August is highest, which coincides with the highest probability of the occurrence of oxygen-depleted water. In summer, waters are weakly mixed due to the presence of strong stratification caused by climate condition and excessive tributaries inflow to the bay and decomposition of organic matter produced by algal blooms during summer in bottom water having limited oxygen supply due to stratification, caused the formation of oxygen deficit bottom water mass in the inner part of the bay. Under some wind conditions,

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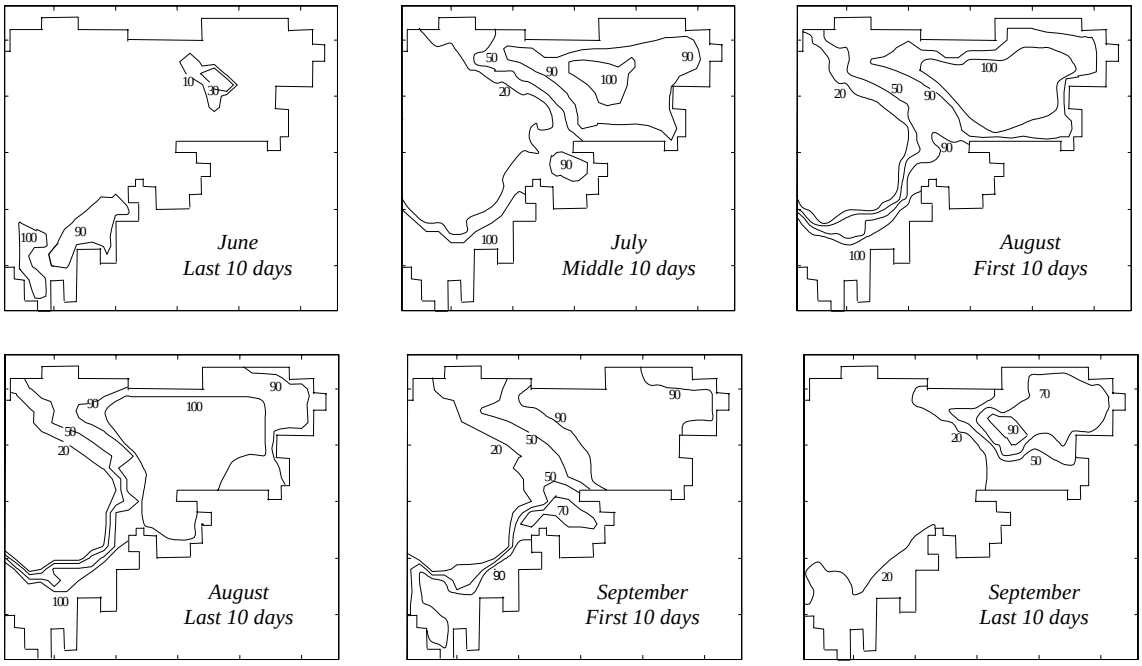

Fig.2 Progressive development and probability of occurrence of hypoxic water at the bottom of the inner bay averaged over 20 years' simulations from 1980-1999.

upwelling of oxygen-depleted bottom water may occur, causing hypoxia condition to some extent at surface water and also causing damage of fisheries. Model results show that the upwelling is occurred every year at the head of the bay. Multiple regression analysis of the probability of occurrence of hypoxic condition at surface water at (H-1) and the observed wind conditions for twenty years shows that the northerly or the north-westerly wind has positive correlation with the development of hypoxic condition at surface water at the north edge of the bay and upwelling of bottom oxygen-depleted water to the surface. Occurrence of hypoxic condition to the surface water occurs under strong offshore winds either northerly or north-westerly winds, which confirmed the upwelling phenomena of the enclosed bay [3].

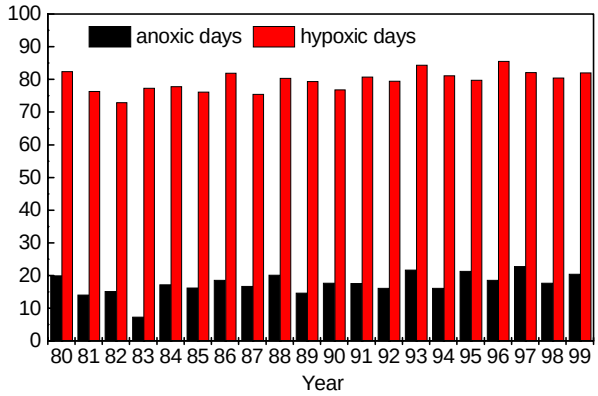

Fig.3 Model results of the existence of anoxic and hypoxic conditions in the inner Hakata Bay.

Model computation of the duration (in days) of hypoxic and anoxic conditions at H-1 (22,3) is shown in Fig.3. This figure indicated that the meteorological conditions have a strong influenced on the development of oxygen-deficit water mass in the bottom. The existence of anoxic condition under the meteorological condition in the year 1983 is lowest.

4. Conclusions

A methodology of assessing of the probability of occurrence of oxygen-depleted water condition, which represents an indirect measure of the spatial and temporal damage and degree of harmfulness caused by this event on the ecosystem was presented in this paper. Using the method, the occurrence probability of oxygen-depleted condition due to eutrophication in the shallow water zone of Hakata Bay was investigated. The presence of strong stratification caused by meteorology and freshwater inflow to the bay are the main reason of appearing oxygen-depleted bottom waters in the inner bay. During August, a larger part of the bottom water is experienced by hypoxic condition with high probability of occurrence, which indicates that the possibility of the damage and severity caused by hypoxia on ecosystem including mortality of fish and benthos is also very high in this period. Statistical analysis shows that the upwelling of bottom oxygen-depleted water and subsequent occurrence of hypoxic condition to some extent at the surface water at the head of the bay would occur under strong offshore wind. Moreover, the model used in this study was capable of simulate reasonably the hydrodynamics, thermal structure and water quality processes of the bay, which are the key elements in the formation and analysis of oxygen depleted water mass. The model can be used for other lakes and bays, where knowledge of temperature and density stratification is important for assessing the water quality.

5. References

1. Yanagi, T. (1989). A summary of symposium of oxygen-deficient water mass, *Coastal Oceanography*, 26(2), 14-145.
2. Fujihara et al. (1992). Development of multi-level density flow model and its application to the upwelling generated by artificial structures, *Technical Report*, National Research Institute of Fisheries Engineering, Aquaculture & Fish Port, 14, 13-35.
3. Yoon et al. (1994). Study of upwelling phenomena of anoxic water 'A-oshio, Conference Paper, *Coastal Engineering*, 3447-3461.