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Research Paper

Algal bloom prediction of the lower Han River, Korea using the EFDC hydrodynamic and water quality model

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ABSTRACT

The lower part of the Han River, which flows through Seoul, Korea, experienced excessive toxic cyanobacterial growth in 2015. Modeling of algal bloom occurrence patterns in the lower part of this river was performed using the Environmental Fluid Dynamics Code (EFDC) to understand algal dynamics and thus better develop management alternatives. For a 71 km long river section, 1175 horizontal 2-D grid elements were developed. This grid system was determined adequate, as the maximum values of the Courant–Friedrichs–Lewy condition and orthogonality deviation were 0.5 and 20.1, respectively. Chlorophyll-a (Chl-a) was chosen as the primary indicator for the likelihood of algal blooms. Calibration and verification of EFDC were performed by comparing the model results to three years of field data collected from 2013 to 2015. Calibration accuracy was verified not only for physical variables, including the mean water level and temperature, but also for other water quality variables in various locations of the study area. To improve the prediction accuracy of Chl-a, three dominant groups of algae were considered: diatoms, green algae, and cyanobacteria. The optimum growth temperature ranges were selected based on field data for the study area. It was found necessary to apply different maximum growth rates for algal groups for the upstream and downstream regions of the study area to appropriately reflect field observations. This result indicates that more than three algal groups need to be included to improve Chl-a calibration accuracy for the study area, yet the current EFDC model can consider only up to three phytoplankton groups. Although this problem could be overcome by assigning different maximum growth rates for different regions, it may be necessary to improve EFDC so that it can include more phytoplankton groups.

1. Introduction

The lower section of the Han River, which passes through Seoul City, Republic of Korea (hereafter Korea), experienced a relatively severe algal bloom in 2015. The Korean Government developed a four- level algal warning system by measuring Chlorophyll-a (Chl-a) concentrations and the number of toxic cyanobacteria cells per milliliter. During July and September in 2015, Chl-a concentrations and the number of toxic cyanobacteria were measured at levels greater than 25 mg/m^3 and 5000 cells/ml, respectively. A second level algae warning based on the Korean system was declared in several locations of the river.

An analysis that clearly understands the causes and effects of algal blooms and water pollution within a water body is often very difficult to achieve due to the many factors involved. For example, Chapra (1997) reported that a sufficient level of nutrients in the water body for phytoplankton to feed on, an appropriate water temperature for algal growth, and an adequate amount of light for photosynthesis are all essential conditions for an algal bloom to occur. Reynolds (2006) reported the growth of algae is affected by competition between different algal groups, predation in the food chain, the degree of pollution, and the flow characteristics of the river are important factors. In the case of the lower Han River, many factors can affect algal blooms. It would be difficult to conclude that only one or a few factors would be responsible.

Various methods may be applied to control algal blooms in surface waters. Physical methods, such as dilution or mechanical mixing may be used, but require enormous amounts of energy. Chemical methods such as algaecides or coagulants can be used, but are usually applied to relatively small and stagnant water bodies and are not used for rivers. Biological methods, such as the introduction of predators or constructed wetlands also can be used. All of these methods only deal with surficial symptoms of algal blooms and only last a limited period of time. Therefore, it is necessary to identify feasible water quality management alternatives that can be applied efficiently (Anderson, 2009).

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Water quality modeling is a powerful tool for the comprehensive interpretation of complex water quality interactions (Ambrose et al., 2009). Many different models have been applied to water bodies to analyze which countermeasures may be effective for mitigating algal blooms (Chen and Mynett, 2006; Wong et al., 2007; Los et al., 2008; Leon et al., 2011; Seo et al., 2012; Camacho et al., 2014; Jian et al., 2014). The Environmental Fluid Dynamics Code (EFDC) (Hamrick, 1992) is a versatile surface water model that has been used widely for various water body types such as rivers, lakes, wetlands, dams, estuaries, and coasts for environmental assessment and management. Park et al. (2005) applied the EFDC water quality model in Gwangyang Bay, Korea. Li et al. (2011) applied the concept of water age using EFDC to understand the effect of the migration of dissolved substances on the water quality of Lake Taihu, China. Wu and Xu (2011) and Tang et al. (2016) used EFDC to predict the occurrence of algal blooms in Daoxiang and Taihu lakes in China, respectively. Seo and Song (2015) conducted a three-dimensional hydrodynamic and water quality modeling analysis using EFDC in the Youngsan River, the fourth largest river in Korea. Yin and Seo (2016) analyzed an optimal grid selection for EFDC water quality modeling of the Ara Navigation Channel in Korea. Lee et al. (2017) conducted a study to evaluate the impact of installing of a new sewage treatment plant on the water quality of the Galing River, Malaysia. Although many studies have been carried out, an accurate prediction of the occurrence of algal blooms has been difficult to achieve. Since algae are not simple substances but living organisms, their population dynamics are difficult to explain with simple mass balance equations or chemical processes. Sufficient data is rarely available to estimate boundary conditions, define the parameters of water quality variables, or solve the various algal growth related problems required to perform the modeling.

This study aims to improve the prediction accuracy for harmful algal bloom in the lower Han River, Seoul, Korea so that the model can be used in decision making processes in developing management alternatives. The growth-related parameters of algae groups were selected from the literature and from field observations in the study area, and then further adjusted in the calibration of EFDC. To improve model prediction accuracy for algal blooms in this study, different maximum growth rates were applied for algal groups in regions of the river influenced by different water quality conditions.

2. Materials and methods

2.1. Study area

The Han River is the second largest river in Korea. It is 483 km long and its basin area is 34,428 km^2. This study focuses on a lower 71 km section of the river that passes through Seoul from the Pal-

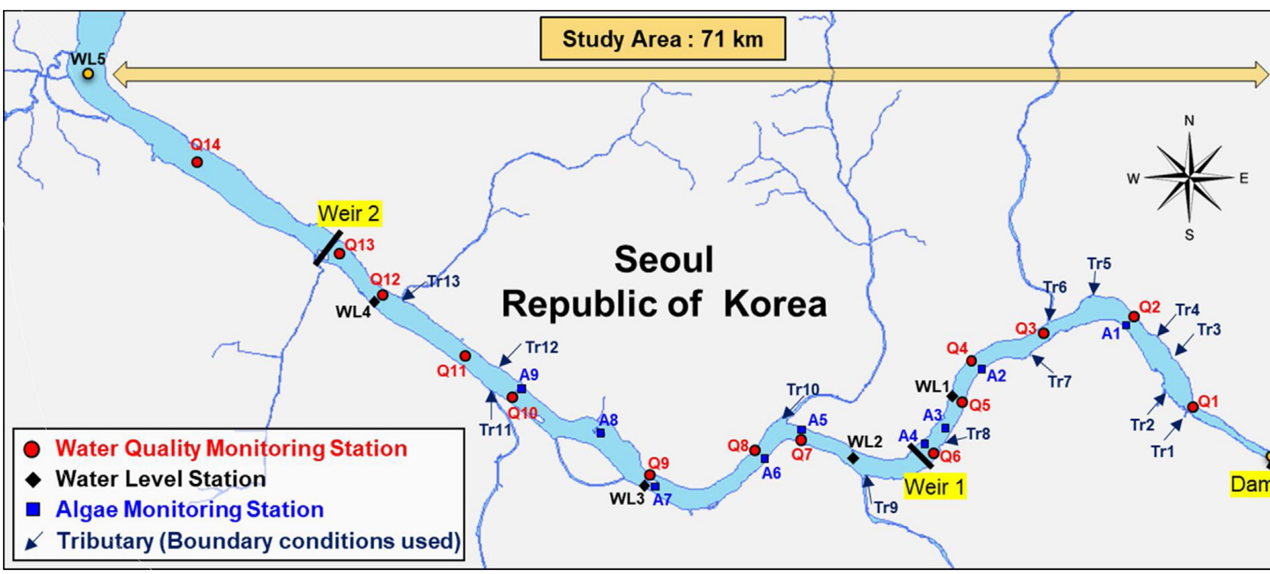

Fig. 1. Monitoring stations and important in-stream structures in the study area.

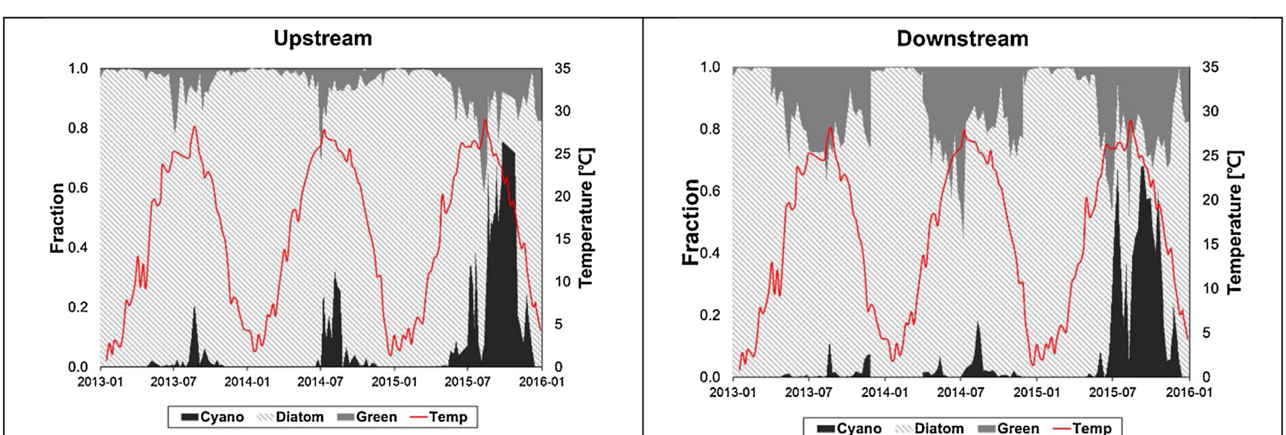

Fig. 2. Fraction of algae in upstream and downstream.

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