Simulation of suspended solid transportation in Lake Suwa, Japan

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Abstract

It is important to understand characteristics of suspended solid transportation in every water area to administer water quality. For that purpose, many researchers have simulated suspended-solid transportation using various models in addition to elucidating characteristics of related external forces (river discharge, wind, etc.). This paper describes a suspended solid transportation simulation of a lake during a flood period and a strong wind period because it was considered that these periods greatly affect the annual budget of suspended solids. Results showed that: 1) Characteristics of density flows (negatively buoyant surface jets) were expressed approximately in the flood period. 2) Erosion/deposition patterns in Lake Suwa in the flood period generated by this model were obtained. 3) Characteristics of sediment resuspension by strong winds were expressed approximately in the strong wind period.

1. INTRODUCTION

Recently, suspended-solid transportation has been studied increasingly from a biophysical viewpoint (e.g., ecosystem, environmental issues) as well as a technical viewpoint (e.g., maintenance of port facilities, dredging). Consequently, studies of suspended-solid transportation in semi-closed water areas are increasing. However, it is important to understand properties of suspended solid transportation in every water area because water area characteristics are different. Many researchers have simulated the transportation of suspended solids (sediment) using various models. Nakagawa [1] used a multi-level hydrodynamic model to reproduce a tidal current field and an advection-diffusion model with bottom boundary conditions for erosion and deposition to estimate the transport rate of fine sediment in the Arika Bay. Kawanishi et al. [2] developed a 3-D baroclinic numerical model with a sediment transport model that realistically simulates cohesive and noncohesive sediments in Hiroshima Bay. Inagaki et al. [3] combined the Tidal Residual Intertidal Mudflat (TRIM) [4] and QETE models [5] and explained the transport mechanism of sediment in the southern San Francisco Bay.

With these points as background, we performed a suspended solid transportation simulation of a lake. In this paper, we specifically describe the flood period and the strong wind period because it was considered that these periods greatly affect the annual budget of suspended solids.
2. ANALYSIS AREA AND GRID INFORMATION

Lake Suwa is located in the center part of Japan (N36°03', E138°05'). The information of this lake is given briefly in Table 1. The Kamaguchi floodgate is the only outflow point. The total catchment areas of the Kami, Miya, Hannoki, Yokokawa, and To Rivers constitute about 90% of all catchment areas. Figure 1 shows a view of Lake Suwa with depth contour lines.

This study was based on unstructured (triangular) grids. The numerical grids were generated automatically by the method of modified Delaunay Triangulation [6] from information of nodes, so that the elements near river mouths, where the variation of velocity was very large, were as small as possible. The number of nodes is 4000; there are 7687 elements. The average area of the individual elements is 1730 m².

<table>
<thead>
<tr>
<th>Table 1: Brief information of Lake Suwa</th>
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<tbody>
<tr>
<td>lake area (km²)</td>
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<tr>
<td>catchment area (km²)</td>
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<tr>
<td>average depth (m)</td>
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<td>maximum depth (m)</td>
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<tr>
<td>the number of inflowing rivers</td>
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<td>the number of outflowing rivers</td>
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3. OVERVIEW OF SUSPENDED SOLID TRANSPORTATION MODEL

The governing equations were quasi-3D Navier-Stokes equations, the conservation law of mass, and the conservation law of suspended solids, considering resuspension and settling. Effects of wind waves are considered in this model. For spatial discretization, the Galerkin method (FEM) was applied. For time discretization, the two-step Lax-Wendroff method was applied [7].
In this study, the model described above [7] was modified as follows to simulate suspended-solid transportation with high accuracy.

1) The effect of density variation resulting from muddy water was incorporated.
2) The critical bed shear stress of sediment was given as a function of the grain size [8].
3) The erosion rate of sediment was defined as a function of the water content and the critical bed shear stress [9].

4. SUSPENDED SOLID TRANSPORTATION DURING THE FLOOD PERIOD

4.1 Simulation conditions
We attempted to simulate the actual flood that occurred from 9/9 8:00 – 9/10 4:00 in 1993. The return period of this flood was estimated as 1.12 years. Boundary conditions (the discharges and the concentrations of SS from inflowing rivers) of the sediment properties were set to values obtained using field measurements [10].

4.2 Expression of negatively buoyant surface jets
The vertical view of the vectors and the concentrations of SS near the river mouth of the To River at 17:00 and 19:00 on 9/9 are shown in Fig. 2. In Fig. 2(a), negatively buoyant surface jets that occur because of muddy water were observable and the high-density area was recognized in the lower layer. As shown in Fig. 2(b), muddy water advanced on the sloping bottom and the Karman head was observed at the pointed end of density flow, as is often reported [11].

![Fig. 2: Vectors and concentrations of SS distribution near the river mouth (vertical plane)](image-url)
4.3 Erosion/deposition patterns in the flood period

The erosion/deposition patterns generated by this model in the flood period are shown in Fig. 3. Erosion, which came to 15 mm at most, was recognized especially around the river mouths. On the other hand, deposition, which came to 1.7 mm at most, was observed in regions at nearly 1000 m distance from each river mouth. The erosion/deposition patterns around river mouths were different in every river. For example, the thickness of erosion in each river mouth of the Kami River and Hannoki River was greater than in those of the other rivers.

![Fig. 3: Erosion/deposition patterns generated by this model in the flood period (+: deposition, -: erosion)](image)

5. SUSPENDED SOLID TRANSPORTATION IN THE STRONG WIND PERIOD

5.1 Simulation condition

We attempted to simulate the strong wind period that occurred from 10/26 to 10/28 in 2004. Figure 4 shows the wind velocity at the Suwa weather station during this period. From the evening of 10/26, a strong wind (max: 11.1 m/s) began to blow from WNW.

![Fig. 4: Wind velocity at the Suwa weather station](image)
5.2 Sediment resuspension by strong winds

Figure 5 shows concentrations of suspended solids, which are calculated and observed at one Point A (see Fig. 1). The water depth of this point is 1.7 m; it was observed 30 cm from the bottom. Refer to Toyota et al. [12] for more detailed information about field measurements. The observed value is greater than the calculated one. The reason can be inferred as described below. 1) The critical bed shear stress, which is a function of sediment properties, might be overestimated. 2) The bed shear stress attributable to wind waves might not be estimated properly because the effects of the wind wave were considered briefly based on small-amplitude wave theory. However, two peaks are recognized in both values. The characteristics of the sediment resuspension by the strong wind were expressed approximately.

![Graph showing variation of suspended solid concentrations](image)

**Fig. 5:** Variation of suspended solid concentrations suspended by a strong wind

6. CONCLUSION

Suspended solid transportation was estimated using a quasi 3-D model considering various effects on suspended solid behavior in a lake during the flood period and the strong wind period. The results are described below.

1) The tendency of density flows (negatively buoyant surface jets) was reproduced in the flood period.
2) Erosion/deposition patterns generated by this model in Lake Suwa during the flood period were obtained.
3) Characteristics of sediment resuspension were expressed approximately in the strong wind period.

Subjects for future study include the following.
1) This numerical model should be improved to provide higher accuracy to reproduce results of field measurements.
2) It is essential to understand the characteristics of the wind in the Suwa District to estimate the annual budget of suspended solids.
7. REFERENCES


