Journal of the Faculty of Enviromental Science and Technology,
Okayama University
Vol. 7, No.1. pp. 39-44, March 2002

A Numerical Analysis and an Experimental Study of an Unsteady Flow in Kojima Lake

Masaji Watanabe*

(Received November 30, 2001)

We present some results of a finite element analysis for an unsteady flow in Kojima Lake. We also present an experimental result . The global positioning system was utilized in the experiment in order to record the temporal and the spatial data of a float traveling with the driving force of the fluid resistance. The spatial and temporal data were recorded to examine their correspondence with analytical results.

Keywords : lake flow, numerical simulation, finite element method, global positioning system

1 INTRODUCTION

Kojima Lake is separated from Kojima Bay with a bank. There are six gates set along the bank in order to control the water level of Kojima Lake. In particular those gates are opened when it is necessary to discharge water from Kojima Lake to Kojima Bay. In May 24, 2001, five of those gates were opened approximately from 14:50 to 18:10. The discharge of water generated an unsteady flow in Kojima Lake. We utilized the global positioning system (GPS) to examine the unsteady flow. A GPS unit evaluates its position analyzing signals from the GPS satellites. We conducted experiments using a float equipped with a GPS unit, which we call the GPS-float, and examined the correspondence between experimental results and numerical results. The one utilized for our experiments also receives signals from a radio beacon to improve its accuracy (differential GPS). The GPS-float receives the driving force generated by the fluid resistance exerted on the plates installed underneath the surface of the water, and travels on the surface while the GPS unit evaluates its position at every fixed time, e.g. at every second. The spatial and the temporal data are transmitted via a wireless modem. These signals are then received by a receiver and recorded to be analyzed. The GPS-float and the data recording system are schematized in Figure 1.

*Department of Environmental and Mathematical Sciences, Faculty of Environmental Science and Technology, Okayama University. This research was supported in part by the Wesco Science Promotion Foundation.

The data obtained in a GPS-float experiment can be utilized to evaluate the result of a numerical analysis, Watanabe (1999), Watanabe (2000) (2), Watanabe (2000) (3), and Watanabe and Kunisada (2001). The movement of the float can be simulated by analyzing the governing equations of the flow and the momentum equation of the float. The correspondence between the analytical results and the experimental results are examined to give an evaluation of numerical analysis of the flow. In Section 2, we introduce a numerical result obtained in a finite element analysis of the unsteady flow. We present some results of a numerical simulation of GPS-float in Section 3.

2 FINITE ELEMENT ANALYSIS OF LAKE FLOW

Kojima Lake is separated from Kojima Bay with a bank which is approximately 1 km long. Figure 2 shows a schematized illustration of Kojima Lake. Figure 3 shows an approximate depth of Kojima Lake base on data obtained at Okayama Prefecture Okayama Development Bureau. The approximate depth was used in an analysis of a flow in Kojima Lake. The inflow through two rivers, Sasagase River and Kurashiki River, is the primary source of water in Kojima Lake. There are six gates set along the bank and they are all 24 m wide, and these gates are opened when a discharge of water from Kojima Lake to Kojima Bay is necessary in order to control the water level of Kojima Lake. On May 24, 2001, five of those six gates were opened approximately from 14:50 to 18:10. By opening of the gates, the water level of Kojima Lake

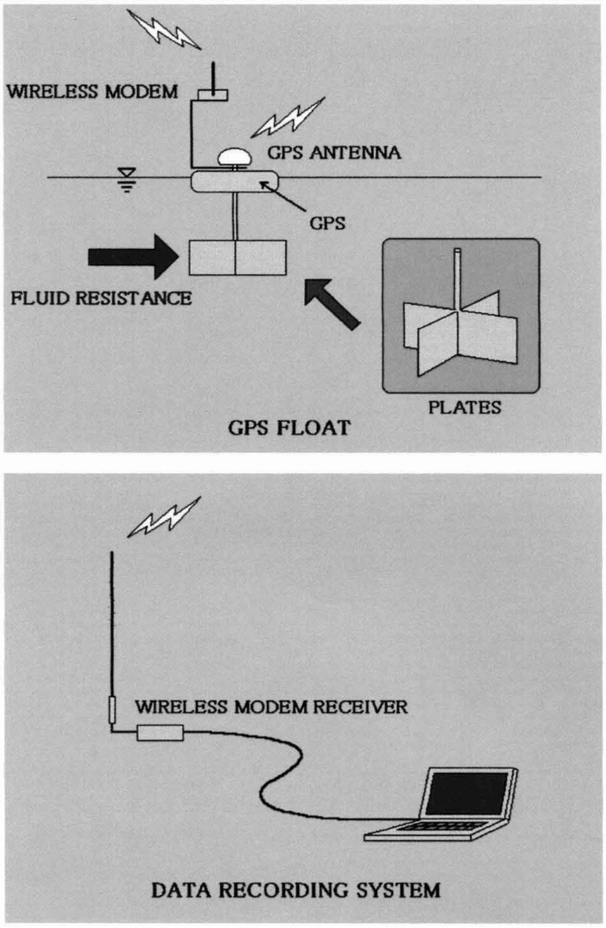

Figure 1: The GPS-float and the data recording system.

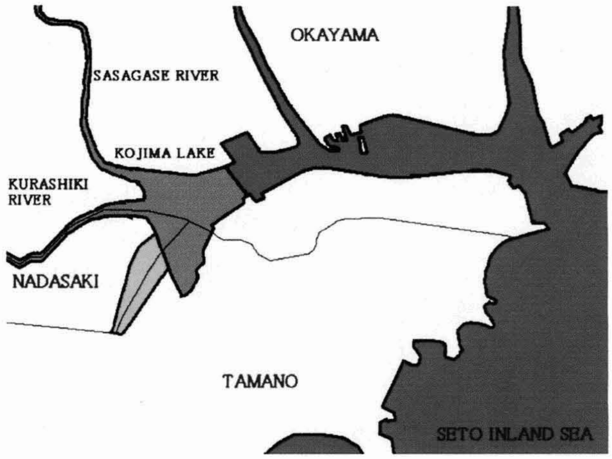

Figure 2: Kojima Lake and its vicinity.

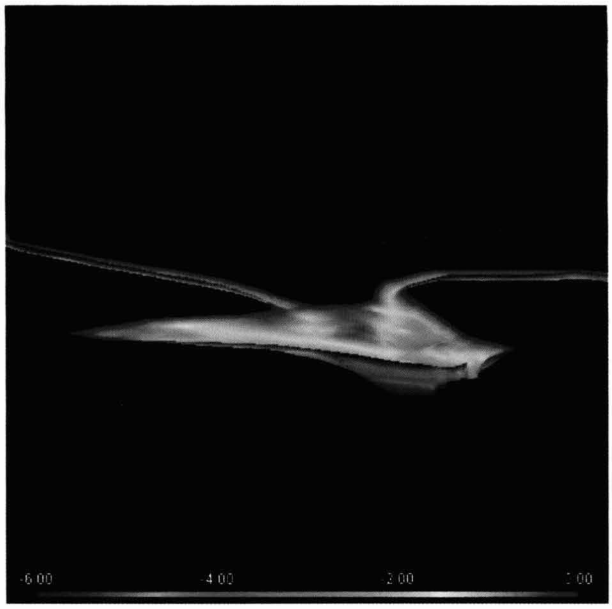

Figure 3: An approximate depth of water

lowered by 0.55 m while the tide level at the Kojima Bay lowered approximately by 0.7 m. Figure 4 shows approximate temporal changes of water levels of Kojima Bay, Kurashiki River, Sasagase River, and Kojima Lake based on data obtained at Kojima Bay Central Administration Office, the Section of Land Improvement in the Kojima Bay Area.

The discharge of water from Kojima Lake into Kojima Bay generated an unsteady flow in Kojima Lake. We analyzed the unsteady flow by applying a finite element method to momentum equations and a continuity equation that govern the temporal and spatial change of the velocity of the flow and the water level. We apply the method used to analyze unsteady flows previously, Watanabe (1999), Watanabe (2000) (1), Watanabe (2000) (2), Watanabe (2000) (3), and Watanabe and Kunisada (2001). Figure 5 shows the division of a region corresponding to Kojima Lake into finite elements.

We analyzed the unsteady flow numerically using the boundary data given by the temporal changes of the water levels of Kojima Bay, Kurashiki River, and Sasagase River which Figure 5 shows. In the numerical analysis, we set the horizontal eddy viscosity coefficient $A_h = 2.0\ \mathrm{m}^2/\mathrm{s}$. Figures 10, 11, 12, and 13 show the velocity vectors in every 1200 seconds after the opening of the gates. Figure 6 shows the comparison between the actual change of the water level in Kojima Lake and the simulated one.

3 ANALYSIS OF GPS-FLOAT DATA

The GPS-float travels receiving the driving force of the fluid resistance exerted to plates installed underneath. These plates are set crosswise to receive the fluid resistance in every direction. While the GPS-float travels on the surface of water, the GPS evaluates its position at every fixed time analyzing signals from the GPS satellites. The temporal and spatial data are then transmitted via a wireless modem. The data transmitted from the GPS-float are received by a receiver to be recorded for an analysis, Watanabe

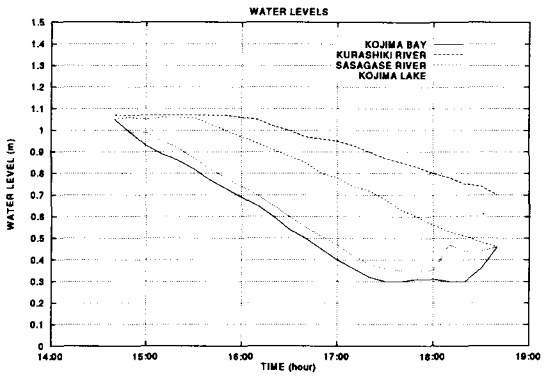

Figure 4: Changes of water levels.

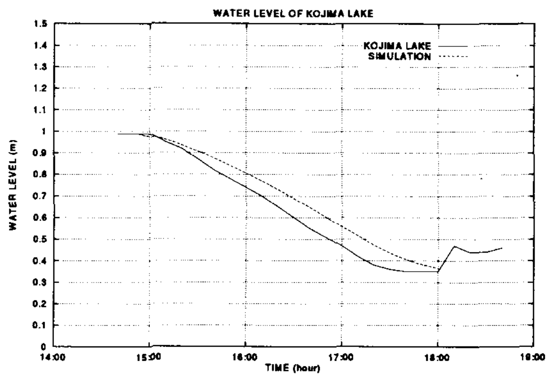

Figure 6: The change of the water level in Kojima Lake.

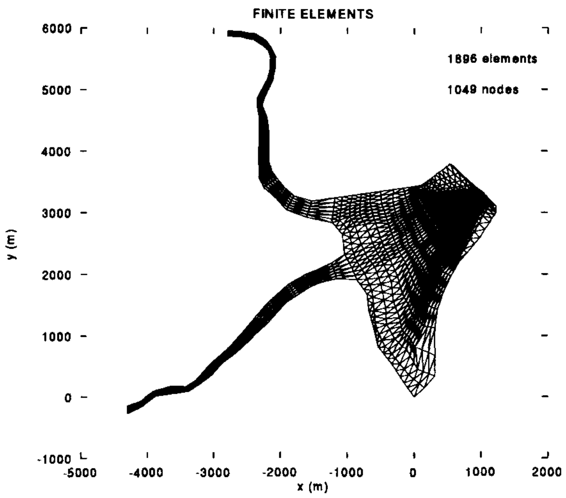

Figure 5: Finite elements of a region corresponding to Kojima Lake

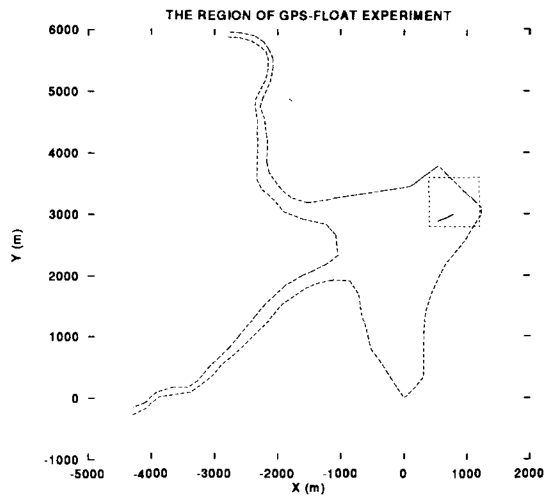

Figure 7: The GPS-float experiment.

(1999), Watanabe (2000) (2), and Watanabe (2000) (3), and Watanabe and Kunisada (2001).

Figures 7 and 8 show the movement of the GPS-float recorded approximately from 15:15 to 15:46. During the experiment the GPS float traveled approximately 277 m, and its average velocity was approximately 0.15 m/s. Figure 7 shows the locus of the GPS float. Figure 8 shows the region indicated by the square which Figure 7 shows. The numbers indicate the time in minutes, which elapsed after the gates were opened. The motion of the GPS-float can be simulated by analyzing the equations governing the flow and the momentum equation of the GPS-float. Figure 9 shows the actual locus of the GPS-float and the simulated one.

ACKNOWLEDGMENTS: I would like to thank people in the Kojima Bay Central Administration Office, the Section of Land Improvement in the Kojima Bay Area for sharing data concerning the water level of the Kojima Lake and the tide level of the Kojima Bay, and people in the Okayama Prefecture Okayama Development Bureau for sharing data concerning the depth of water in the Kojima Lake, and other useful information. I would also like to thank people in the Machining Center, the Faculty of Engineering, Okayama University for building the GPS-float, and those students in the Faculty of Environmental Science and Technology and in the Graduate School of Natural Science and Technology, who kindly helped me with the GPS-float experiment.

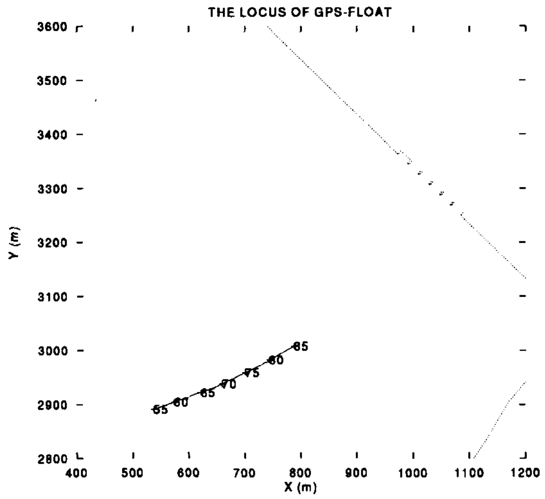

Figure 8: The locus of the GPS-float and elapsed time.

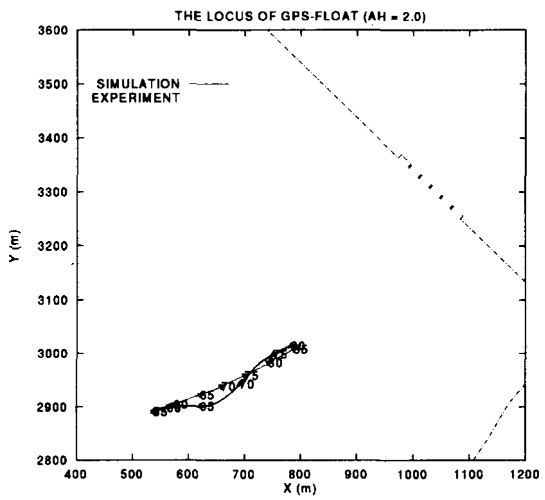

Figure 9: The locus of the GPS-float and its simulation

REFERENCES

Watanabe, M. (1999): A numerical simulation of lake flow and a GPS-float experiment, *The Second International Symposium on Water Environment, Okayama University, Journal of the Faculty of Environmental Science and Technology, Okayama University* (Special Edition), pp. 111-116.

Watanabe, M. (2000) (1): A numerical analysis of unsteady flow in Kojima Lake, *Journal of the Faculty of Environmental Science and Technology, Okayama University* **5**(1), pp. 31-34.

Watanabe, M. (2000) (2): On analysis of unsteady flows in lakes and marshes and its experiments , *Lectures supported by Kogakukai, Science and Engineering Reports of Tohokugakuin University,* **34**(2), pp. 49-53.(in Japanese)

Watanabe, M. (2000) (3): On a numerical simulation of lake flow and its experimental evlaluation, *RIMS Kokyuroku 1198, Numerical Solution of Partial Differential Equations and Related Topics II,* Research Institute for Mathematical Sciences, Kyoto University, Kyoto, Japan, pp. 50-57. (in Japanese)

Watanabe, M. and Kunisada, S. (2001): An experimental evaluation of lake flow simulation, *Journal of the Faculty of Environmental Science and Technology, Okayama University* **6**(1), pp. 11-15.

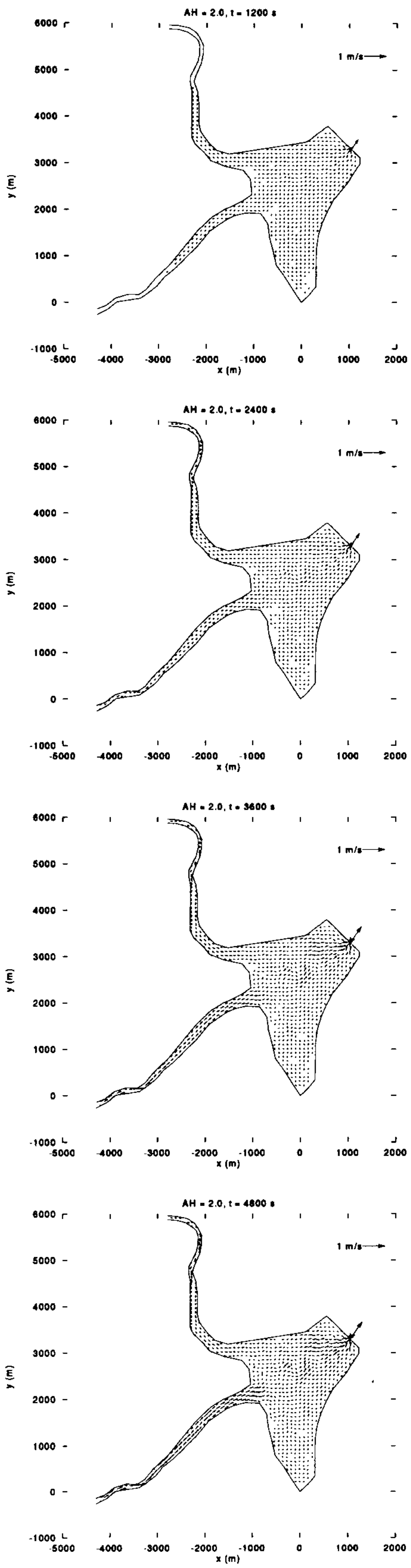

Figure 10: Velocity vectors ($-5000 \leq x \leq 2000$, $-1000 \leq y \leq 6000$). t = 1200 s, 2400 s, 3600 s, 4800 s.

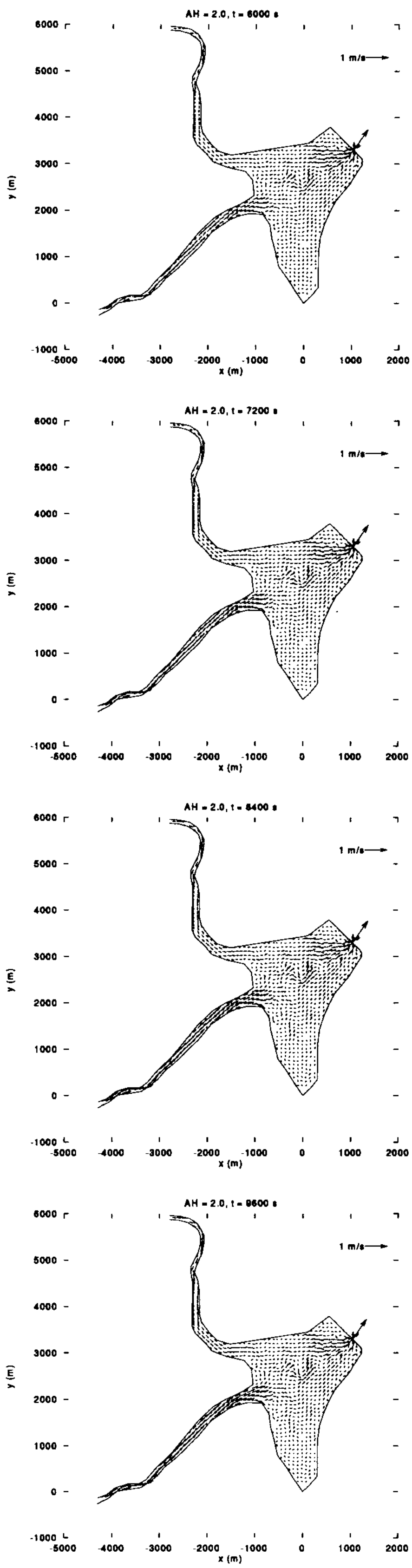

Figure 11: Velocity vectors ($-5000 \leq x \leq 2000$, $-1000 \leq y \leq 6000$). t = 6000 s, 7200 s, 8400 s, 9600 s.

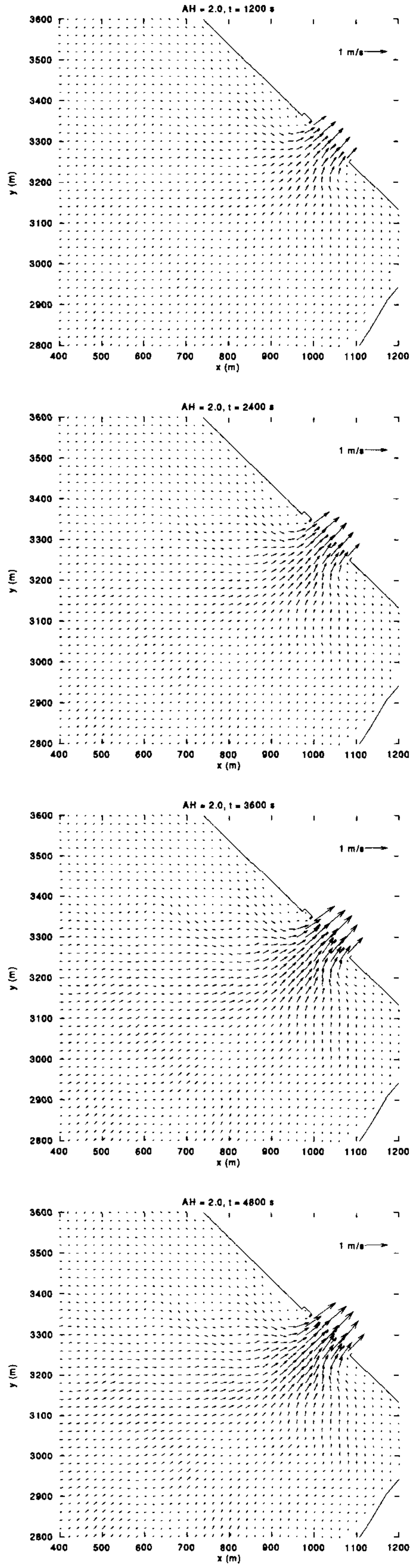

Figure 12: Velocity vectors ($400 \leq x \leq 1200$, $2800 \leq y \leq 3600$). $t = 1200$ s, 2400 s, 3600 s, 4800 s.

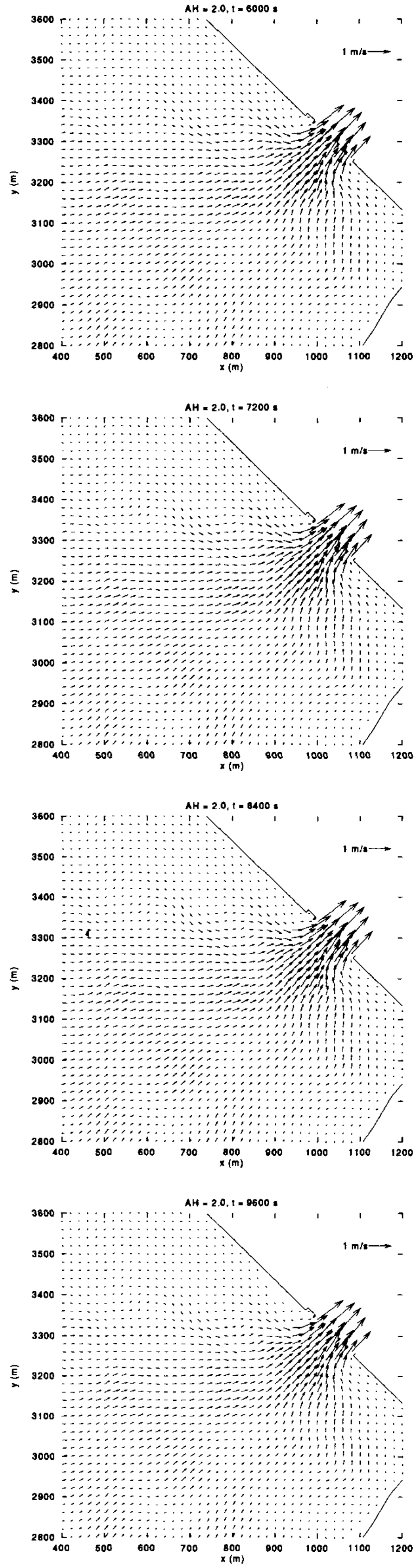

Figure 13: Velocity vectors ($400 \leq x \leq 1200$, $2800 \leq y \leq 3600$). $t = 6000$ s, 7200 s, 8400 s, 9600 s.