Proc. of the 5th IAHR Europe Congress — New Challenges in Hydraulic Research and Engineering
Editor(s) Aronne Armanini and Elena Nucci
doi:10.3850/978-981-11-2731-1_080-cd

Response of a highly-stratified microtidal estuary to sudden changes in the river flow

N. Krvavica, I. Ružić & N. Ožanić
Faculty of Civil Engineering
University of Rijeka, Croatia

ABSTRACT

The stratification in the microtidal Rječina River estuary was examined during sudden changes of the river flow rates. The intrusion lengths and propagation rates of the salt-water layer were also investigated using a one-dimensional two-layer numerical model.

1 INTRODUCTION

In microtidal conditions and under dominant river influence a highly stratified estuary is formed at the river mouth. In these conditions, the vertical structure of the estuary is defined by an upper layer of fresh water flowing downstream over a lower salt-water layer which intrudes upstream. The length of the salt-water intrusion and the stratification strength are governed by the river flow rate Q and tidal dynamics. The main aspects of these physical processes can be simulated by two-layer shallow water numerical models [1, 2]. The behaviour of highly-stratified estuaries under steady and gradually changing conditions is well understood. However, the response of the two-layer structure to sudden changes in the river flow still remains an open area of research.

In this study we examined the salt-water intrusion lengths and stratification strength in the Rječina River estuary in Croatia under highly variable river flows. The results are obtained from the field measurements [3, 2] and numerical simulations using the STREAM-1D [1, 2], a one-dimensional (1D) two-layer estuarine model based on a finite volume method (FVM).

2 RESULTS

The river flow rate Q in the lower part of the Rječina River estuary is governed mainly by the overflows from the hydropower plant (HPP) Rijeka [4]. On July 1st 2015, HPP Rijeka started and stopped on two occasions in an eight-hour period, which caused sudden changes in the upstream river flow rate, Q ranged between 4.2 and 13.9 m^3 s^{-1} (Fig. 1). Over the same time period, the sea water level changed only slightly by 20-30 cm. To observe the response of the upper and lower layer to these flow variations, the vertical salinity profiles were measured at 8 different stations along the 1 km long estuary every 15 minutes.

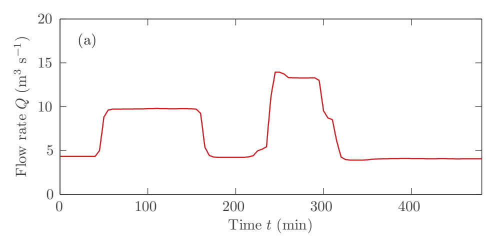

Figure 1: River flow rate on July 1st 2015

The STREAM-1D was applied to compute the layer profiles along the Rječina River estuary under unsteady flow conditions. The upstream and downstream boundary conditions were forced by the river inflow, which corresponded to the observed river hydrograph (Fig. 1), the critical upper layer depth and the total depth at the mouth, which corresponded to the observed sea-levels. The interfacial friction factor was previously calibrated for the Rječina River estuary [3] (it was considered constant along the wedge, but varied in time corresponding to the upper layer flow rate).

Figure 2 presents the computed and observed longitudinal profiles along the estuary at different time steps. The numerical results and field observations show that the estuary structure responded almost instantly to changes in the river flow rate. When Q increased, the salt-water layer receded downstream towards the mouth, and *vice versa*.

3 DISCUSSION AND CONCLUSION

Numerical simulations showed that during a variable river flow the salt-water intrusion length L varied between 600 m and 375 m. Figure 3 shows the propagation rates of the salt-water front computed as a time derivative of L. During the first wave, the salt-water layer front receded at a rate of -0.06 m s^{-1}. When Q decreased, the front advanced upstream at a rate of 0.1

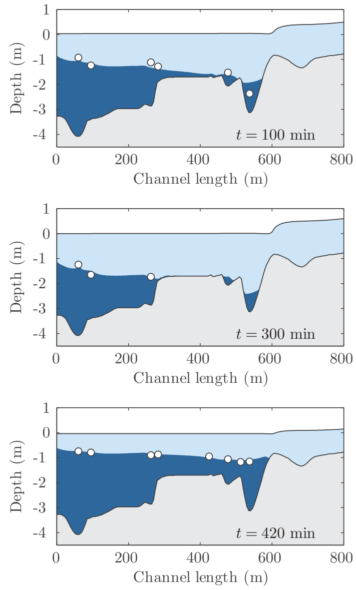

Figure 2: Computed (light- and dark-blue) and observed (circles) two-layer structure along the Rječina River estuary at different time steps

m s^{-1}. Similarly, during the second wave, when Q increased, the salt-water front receded at a rate of -0.15 m s^{-1}, and when Q decreased, the front advanced at a rate of 0.1 m s^{-1}.

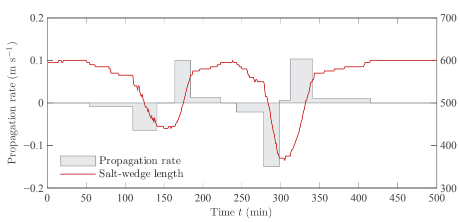

Figure 3: Computed propagation rates and intrusion lengths

Based on the measured vertical salinity profiles in the Rječina River estuary, the stratification strength was also examined using the buoyancy frequency N^2, which varied slightly from 0.3 to 1.3 s^{-2} under variable Q (Fig. 4). During the rising flow, the salt-water front receded towards the river mouth, and the interfacial layer became more diffused, which weakened the stratification. After a force equilibrium was established, highly stratified conditions were quickly restored. During the falling river flow, on the other hand, the salt-water front advanced upstream, but the stratification was unaffected. The average salinities in the upper and lower layer remained almost constant during all stages of the flow rate variations.

To summarize, the two-layer structure in the estuary responded almost instantly to the river inflow. The results indicate that the propagation rates of the salt-water layer are positively correlated with the river flow rate, *i.e.*, higher the increase in the river flow

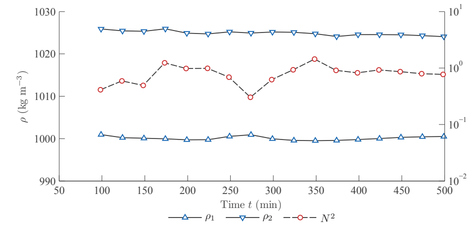

Figure 4: Observed layer densities and stratification strength

rate, higher the propagation rate. However, this dependence was not true for the upstream propagation rates, which were nearly the same in both cases. Furthermore, it seems that sudden increases of the river flow rates negatively influence the stratification of microtidal estuaries; however, highly stratified conditions remained persistent throughout the observed period.

4 ACKNOWLEDGE

This work has been supported in part by Ministry of Science, Education and Sports of the Republic of Croatia under the project Research Infrastructure for Campus-based Laboratories at the University of Rijeka, number RC.2.2.06-0001. Project has been co-funded from the European Fund for Regional Development (ERDF).

REFERENCES

[1] Krvavica, N., Kožar, I., Travaš, V. and Ožanić, N., 2017. Numerical modelling of two-layer shallow water flow in microtidal salt-wedge estuaries: finite volume solver and field validation. Journal of Hydrology and Hydromechanics, 65(1): 49-59.

[2] Krvavica, N., Travaš, V. and Ožanić, N., 2017. Salt-Wedge Response to Variable River Flow and Sea-Level Rise in the Microtidal Rjeina River Estuary, Croatia. Journal of Coastal Research, 33(4): 802-814.

[3] Krvavica, N., Travaš, V. and Ožanić, N., 2016. A field study of interfacial friction and entrainment in a microtidal salt-wedge estuary. Environmental Fluid Mechanics, 16(6): 1223-1246.

[4] Krvavica, N., Mofardin, B., Ružić, I. and Ožanić, N., 2012. Measurement and analysis of salinization at the Rječina estuary. Gradevinar, 64(11): 923-933.