Preprint

HYDRODYNAMIC MODELLING ASPECTS IN THE RESTORATION PLANNING OF A COASTAL WETLAND

TAMÁS KRÁMER, JÁNOS JÓZSA
Budapest University of Technology and Economics,
Műegyetem rkp 3. Kmf. 8., H-1111 Budapest, Hungary
Tel: 36-1-463 2862; E-mail: kramer@vit.bme.hu, jozsa@vit.bme.hu

JUHA SARKKULA
Finnish Environment Institute, Käsekatu 6, FIN-00260 Helsinki, Finland
Tel: 358-9-4030 0237; E-mail: juha.sarkkula@vyh.fi

ABSTRACT: The paper deals with a 100 ha wetland in an estuary of the capital area of Finland. The area has gone through major changes in the last decades due to land based and river borne nutrient loads, resulting in unfavourable living conditions for aquatic birds. In order to restore the overgrown areas, opening inner ponds and brook channels by dredging is planned, in combination with dam construction. A survey of geological, hydrological and hydrodynamic conditions in the wetland has been made as a basis for the planned measures. Numerical models were used to assess the impacts of the dredging work on the water exchange and water levels in the wetland. The hydrodynamic model calculates the wetting and drying as well as water exchange due to the sea level variations. A simplified water balance model estimates the long-term impacts of rainfall-runoff, evapotranspiration and infiltration. The paper presents results of planning scenarios, where alternative pond and brook channels have been designed, controlled by dams with various crest height.

1 INTRODUCTION

Vegetation-covered coastal areas offer excellent conditions for aquatic birds and, consequently, their protection and restoration has become an important environmental issue. The Bay of Viikki-Vanhankaupunginlahti (Figure 1) is a valuable bird habitat of that kind in Helsinki, Finland. Its wetland ecosystem has gone through big changes in the last decades, due to land rise and eutrophication process caused by land- and river-borne nutrient loads. Water protection measures made in the last years have improved the water quality of the Bay and the state of its bottom (Mikkola-Roos and Oesch, 1998). The improvement of the water quality has not, however, restored the area to a condition optimal for a bird habitat. In fact, the overgrowing of the open water ponds and brook channels has significantly disrupted the living conditions of aquatic birds.

One of the most effective measures to restore the overgrown areas is the removal of vegetation by dredging. It is also important to change the hydrodynamic conditions in order to be able to control and sustain the desired water levels, water exchange and ecological conditions. However, prior to the planning and implementation of restoration measures it is necessary to explore the main hydrodynamic features by hydrodynamic measurements and mathematical models. The plans consist of various schemes of opening the ponds and channels by dredging, in combination with

Manuscript of a paper to appear in:
CD-ROM Proceedings of the XXIX IAHR Congress, Beijing, 2001.

dam construction. The calibrated mathematical models can be used to evaluate the hydrodynamic and hydrological conditions for the various schemes to find favourable restoration measures.

2 FIELD MEASUREMENTS

Three high-resolution *Telog* water level recorders were deployed in the open water ponds (*Pond 1, 2, 3,* as indicated in Figure 1) for more than three months. The sea level data was furnished by the Finnish Institute of Marine Research (FIMR) from the permanent gauging station in Helsinki.

The topography was recently surveyed (Toivonen, 1999). Despite the difficult conditions, 134 points were measured in the central part of the wetland. Although core samples were also taken at each point, the detailed information of the upper soil structure was not used in this work. Digital terrain models with 10 m as finest grid resolution were produced using the survey data. As can be seen in Figure 1, the reed covered zones lie 10–50 cm above the 0 sea level. The open water ponds are in the depressions with a bottom level of –10 to –45 cm.

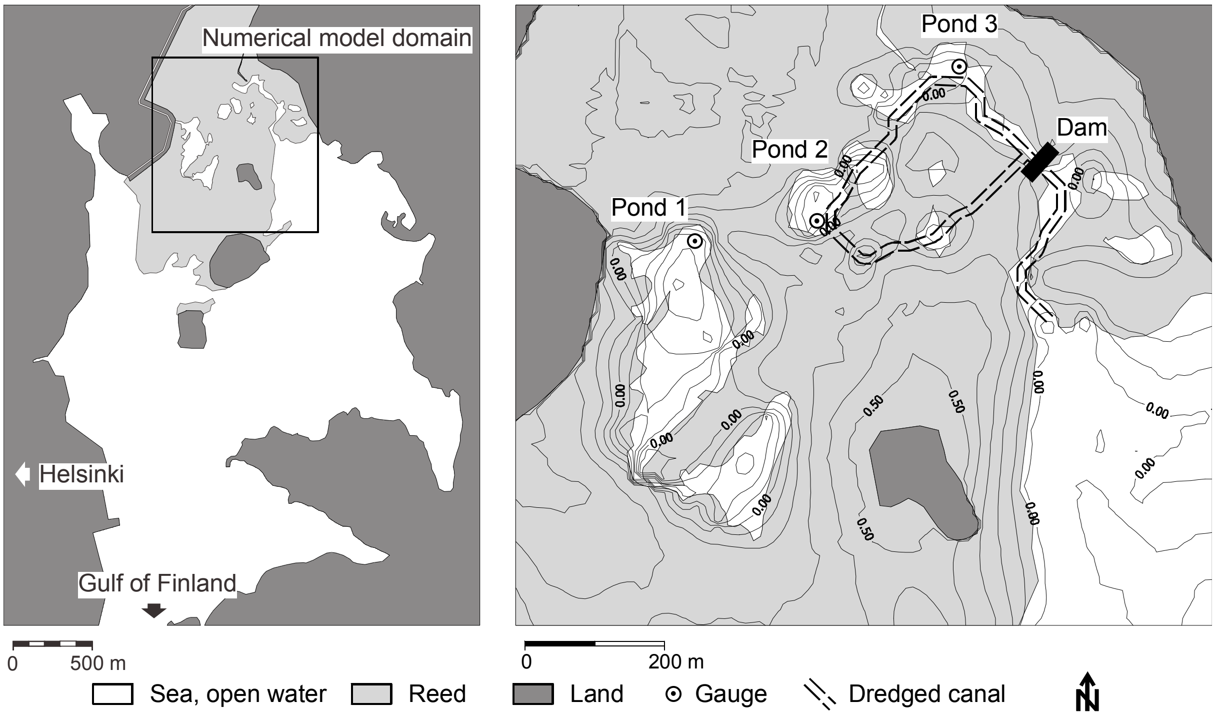

Figure 1. Overview of the study area. Left: Position of the domain of the detailed numerical model. Right: Layout of the central part of the wetland, showing also the water level measurement sites.

3 HYDRODYNAMIC MODEL

Due to the shallowness and the efficient vertical mixing, a general-purpose two-dimensional unsteady flow model is used (Krámer and Józsa, 2000). The vertically integrated governing equations are approximated by a method of finite differences. The flow variables and the topography are discretised on a two dimensional, horizontal Cartesian grid. Time marching is handled with explicit Euler time integration.

Cells being flooded or dried during the calculation tend to introduce numerical instabilities in the solution, resulting for example in negative water depths or unphysically high velocities. Flooding and drying arises in a wide range of free-surface hydraulics problems, such as tidal floods, dam breaks and overland flow of precipitation, hence various techniques have been proposed to handle it. These techniques include deformable computational meshes, modified equations in very shallow regions (e.g. Meselhe and Holly, 1993), and, recently, shock capturing schemes (e.g. Tchamen and Kawahita, 1993). The applied model belongs to the second group, it considers a cell dry if the depth there is below a small critical value (2 cm).

The sea level is prescribed as boundary condition along the open boundary. A special internal boundary condition is applied to determine the flow above the planned dam (see Restoration alternatives). The model gradually switches from a weir formula to the shallow water equations, based on the submergence of the dam.

Flow resistance is represented by the Manning-Strickler friction formula on the whole domain. Different but constant bottom smoothness is assigned to reed and to open waters. Though media properties change with the water depth (King and Roig, 1991), this uniform approach is justified by the fact that the reed stems emerge from the water even during the highest floods.

4 LONG-TERM WATER BALANCE MODEL

A different model was developed for assessing the long-term water balance of the Viikki wetland. This model contains a simplified geomorphic method to describe the flooding and drying. The water is set to the sea level along the open boundaries. All the cells that are hydraulically connected to the open boundaries are immediately flooded or drained to that level, therefore the resulting water surface is always horizontal. Though much faster to calculate, this approach does not account for the propagation speed of the flood wave.

Precipitation is distributed in the modelled area of the wetland so that overland flow follows the steepest descent until it reaches the closest flooded area. The water level of the recipient rises according to the volume of runoff. The small area of the wetland permitted the assumption of zero concentration times without resorting to more sophisticated overland flow models (see e.g. Lee and Yen, 1997). The loss by interception and infiltration is represented by reducing the precipitation by a runoff coefficient.

The catchment area of the Viikki wetland is 2.4 km^2; half of which covers a built-up area. The only effluent enters on the northern side of the wetland. The discharge is calculated using the precipitation intensity with a delay of approximately 12 hours.

Evaporation in the open waters and evapotranspiration in the reed-covered parts contributes to the drying of the wetland. Representative figures were found using the average monthly evaporation of similar wetlands near the study area. The present study did not attempt to model the groundwater flow and the exchange with the surface waters through seepage. Instead, loss by evaporation, evapotranspiration and infiltration are treated collectively.

5 MODEL CALIBRATION

The hydrodynamic model was calibrated by tuning the topography as well as the reed smoothness coefficient. The elevation of the crests separating the ponds greatly affects the water exchange, especially during periods when the sea level falls into the same range. Therefore a two-day long period was chosen from the 1999 measurements, during which a small scale flood reached the wetland. An overall best fitting of the phase, amplitude and damping of the water levels allowed the estimation of the reed smoothness ($k_{reed} = 6\ m^{1/3}/s$) and the crest elevations.

The calibration of the long-term model was done for a period with low sea levels, with a time step of 12 hours. Calibration was essentially based on the measurements of the only gauge at *Pond 1* that stayed submerged also during low-water episodes. A satisfactory agreement between the measured and calculated water levels could be reached. As a result, the rate of evaporation and runoff coefficient could be estimated. Due to the overtopping of the crests, the inflow rate could not be fully deduced from the gauge data. The analysis indicated that the hydraulic connectivity between *Pond 3* and the sea was too high to be justified. This was later confirmed by additional survey work, which revealed the presence of a small stream there.

6 RESTORATION ALTERNATIVES

In order to retain water in the wetland, a fixed dam was proposed in a narrow place close to the sea. In addition to the dam, canals would be dredged for improving water conveyance. This paper presents the canal system comprising 5 m wide, 50 cm deep canals (illustrated with dashed lines in Figure 1) connecting *Pond 2*, *Pond 3*, the dam and the sea. The enclosed reed island is expected to offer a protected environment for birds. Besides the arrangement of the canals, the dam height was also varied. The results with 17 cm crest level are shown here.

The effect of the interventions on the dynamic behaviour of the system was investigated with the hydrodynamic model. Simulations were run for the three-day storm surge already used during the calibration. The flooding and drying of the wetland was assessed using the maps of flood arrival time and highest inundation level. Not only are these aspects vital for the ecosystem, they also help to investigate the spatial and temporal behaviour of the flood. With the help of the flood arrival time map, the penetration of the sea surge can be tracked. The highest water levels during the simulation are presented in Figure 2 for the original state (left) and with the restoration measures (right). Due to the dynamic behaviour of the sea level, the ponds could not be filled up to a uniform level. The highest inundation level and the horizontal extent of the flooded regions is substantially enhanced by the construction of connecting canals, because the flood wave is much less attenuated when propagating along the canals. The volume of water retained behind the dam at the end of the storm surge is a good measure for the effectiveness of the various crest level–canal layout combinations. The presented alternative retains one third more water from the investigated sea storm surge than the present state, because it makes the middle ponds accessible also for lower water levels by cutting through the natural ridges.

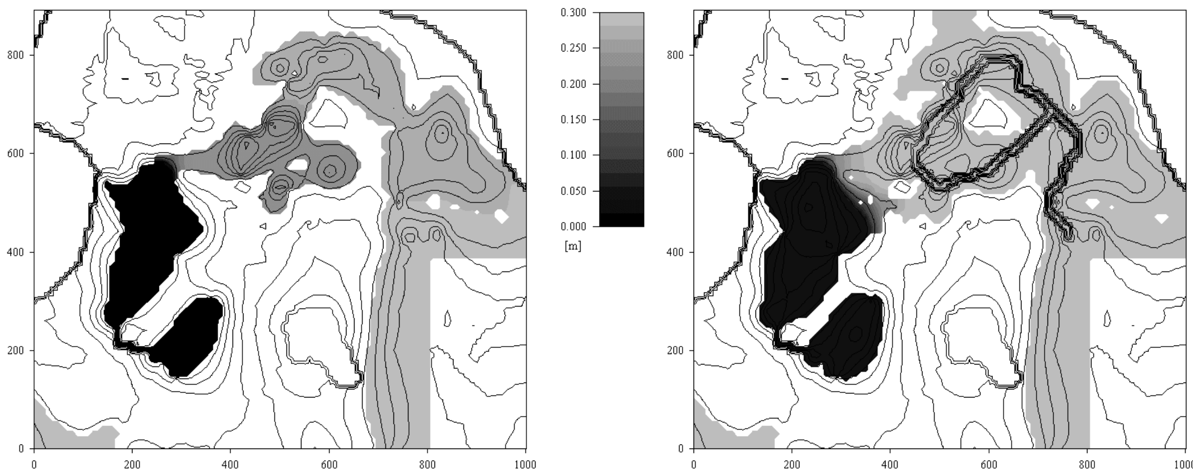

Figure 2. Highest water levels (in metres) for the present state (left) and the restoration alternative (right). Contours show the 10 cm isolines of the topography.

The comparison of the long-term behaviour is also shown here (Figure 3). Because the water level measurements in the ponds were incomplete, the present state is represented with the calibrated model results rather than directly with the measurements. With the improvement measures, the runoff waters inundate in general a larger portion of the inner areas before leaving to the sea over the dam. During the selected period, the inflow from the catchment was not sufficient to fill the wetland up to the crest level. Not surprisingly, the ponds connected via the dredged canal (*Pond 2* and *3*) behave identically.

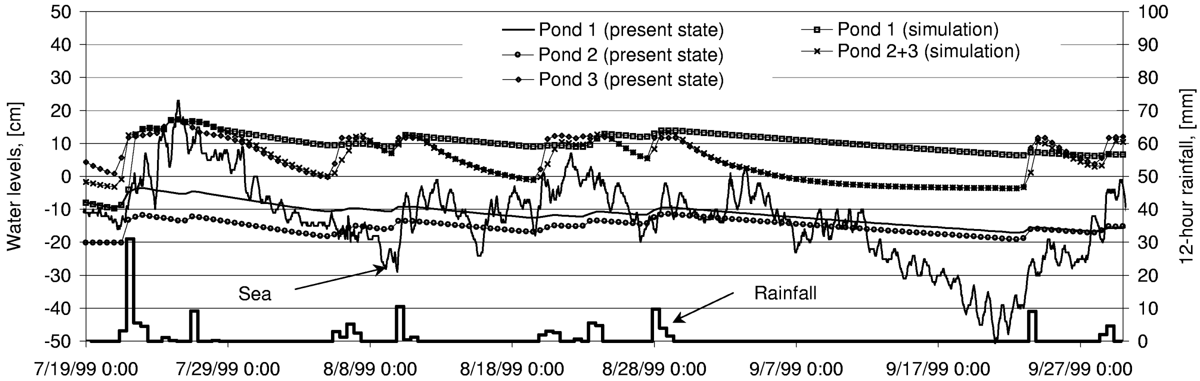

Figure 3. Long-term simulation. Comparison of the simulations for the present state and after the intervention.

To investigate the effect of an artificial freshwater recharge to the wetland, it is important to determine the volume of water necessary to reach a desired water level in the ponds. Here a recharge to *Pond 3* is examined. Water is supplied to the wetland and the evolution of water levels in the three ponds is followed for the restoration alternative (Figure 4). This analysis shows that approximately 27 000 m^3 water needs be recharged to reach the crest level of the dam. Further recharging would then overtop and leave to the sea.

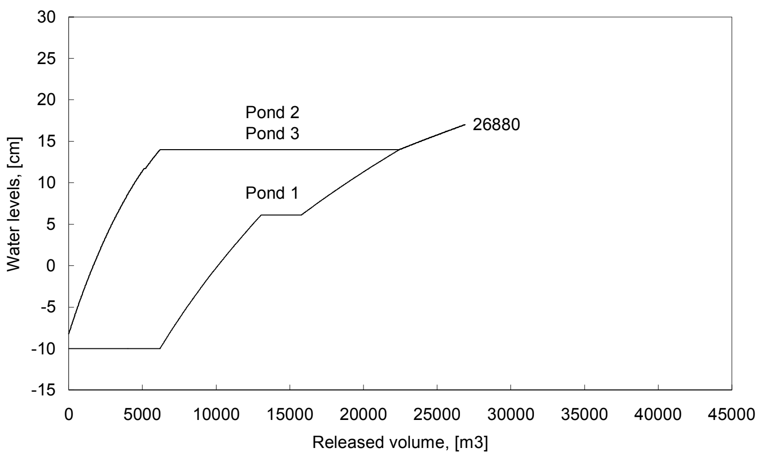

Figure 4. Increase of the water level in function of the recharged volume.

7 CONCLUSION

To support the planning of the Viikki-Vanhankaupunginlahti Bay, the water exchange of the wetland was explored with numerical models. Short-term processes were modelled using a hydrodynamic model based on the shallow water equations. Processes with longer time scale were investigated with a water balance model. Nevertheless, it was found that the forcing of the sea is typically so slow that the wetland adjusts itself with little delay. The slopes in the wetland are very gentle, therefore the flooding and drying is extremely sensitive on the accuracy of the topography, as was also reported by Marks and Bates (1998) in the case of 2D river flow simulation. The models made use of recent measurements for input and calibration.

Several restoration alternatives were investigated with the calibrated models. The water retention of the system was examined with different crest levels of the proposed dam and different networks of dredged canals. The results with one particular variant are discussed in this paper. The canals facilitate the intrusion of the sea flood waves to the dam and to its vicinity in two ways: they offer less flow resistance and they cut trough the ridges separating the ponds. However, the innermost parts are not directly affected by the interventions, because they will be flooded and drained more efficiently with the improved connection to the sea through the canals. A higher crest level of the fixed dam has two opposing effects: it hinders the drainage of the wetland but also keeps out lower sea floods. It certainly retains more of the inflow from the catchment area.

8 REFERENCES

King, J. P.; Roig, L. C.: Finite element modelling of flow in wetlands. *Proc. Hydraulic Engineering*, ASCE, held in Nashville, Tennesse, 1991; 286–291.

Krámer, T.; Józsa, J.: SWAN: a Shallow WAter Numerical modelling environment. To appear in: *Proc. International Workshop on Refined Flow and Transport Modelling in Shallow Water Environment*, held in Budapest, Hungary, 2000.

Lee, K. T.; Yen, B. C.: Geomorphology and kinematic-wave-based hydrograph derivation. *J. Hydr. Eng.*, ASCE, 1997; 123: 73–80.

Marks, K; Bates, P.: Integration of high resolution topographic data with floodplain flow models. *Proc. 3rd International Conference on Geocomputation*, held in Bristol, UK, 1998.

Meselhe, E. A.; Holly, F. M.: Simulation of unsteady flow in irrigation canals with a dry bed. *J. Hydr. Eng.*, ASCE, 1993; 119: 1021–1039.

Mikkola-Roos, M.; Oesch T.: Viikki-Vanhankaupunginlahti nature reserve – Ecological state, restoration and management plan, City of Helsinki Environment Centre, Helsinki, 1998. (In Finnish)

Tchamen, G. W.; Kahawita, R.: The numerical simulation of wetting and drying areas using Riemann solvers. *Proc. Modelling of flood propagation over initially dry areas*, held in Milan, Italy, 1994.

Toivonen, T.: Viikki-Vanhankaupunginlahti – Survey of the organic topsoil, Geological Survey Finland, Espoo, 1999. (In Finnish)