2D SIMULATION OF WATER DEPTH AND FLOW VELOCITY USING THE MIKE 21C MODEL

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ABSTRACT

In the present work the MIKE 21C hydraulic model is used to simulate the water depth and flow velocity at the downstream section of the Koiliaris River Basin in Crete-Greece. MIKE 21C is an advanced mathematical modeling system, which has been developed specifically to simulate 2D flow and morphological changes in rivers. The model is based on an orthogonal curvilinear grid, which has the advantage of computational speed over other types of grids. The hydrodynamic part of the model is based on the Saint-Venant equations. Initially, 2D files of the curvilinear grid and bathymetry were generated and introduced to the model. Time series for discharge, water level and the initial surface water elevation from hydrometric stations were also introduced as inputs. The model was calibrated using water level field data that were collected during high and low flow discharges. Following the model calibration, the 2D vectors maps of flow velocity and water depth were produced. Using the obtained simulation results, extreme hydrological events (floods, droughts) can be adequately monitored in the study area.

Keywords: MIKE 21C model, hydraulic model, flow velocity, flow depth, discharge

1. Introduction

Various numerical models have been developed for river flow simulation, which solve the governing equations using certain computational algorithms. These models are divided into two main categories: one-dimensional (1D) and two-dimensional (2D) (Kourgialas and Karatzas, 2013). One-dimensional numerical models are mostly based on finite difference and finite element methods. The finite difference method is more popular because of the comparatively small computational time. Different software tools, such as the HEC River Analysis System model from the US Army Corps of Engineers (USACE1, 2002) and the MIKE 11 hydraulic model developed at the Danish Hydraulic Institute (DHI, 1997), have been used extensively for the dynamic 1D flow simulation in rivers. One-dimensional models, although simple to use, fail to provide detailed information regarding the flow field. The most widely used software packages for 2D modelling are the MIKE 21 model (DHI, 2007) and the FLOW 2D model (O'Brien, 2006). Two-dimensional modelling has the advantage of flow propagation simulation with great accuracy. Nevertheless, the disadvantage of 2D models is that they require substantial computational time and a fine river grid. This limitation can be overcome by applying the MIKE 21C two-dimensional model.

The purpose of this study was to simulate river flow velocity and flow depth with the 2D hydraulic model MIKE 21C. The main advantage of this model is that it is based on a curvilinear (boundary-fitted) grid where the grid lines follow the bank lines (MIKE 21C, 2011a). The curvilinear grid makes the MIKE 21C model a suitable tool for fast and detailed simulation of river hydraulics and sediment transport.

2. MIKE 21C model description

MIKE 21C is a two-dimensional mathematical model for the simulation of water level, flow and sediment transport in rivers and estuaries. The hydrodynamic part of the model solves the vertically integrated Saint-Venant equations (continuity and conservation of momentum) in two directions (MIKE 21C, 2011b).

The equations solved in MIKE 21C are:

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial s}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial n}\left(\frac{pq}{h}\right)+2\frac{pq}{hR_n}+\frac{p^2-q^2}{hR_s}+gh\frac{\partial H}{\partial s}+\frac{g}{C^2}\frac{p\sqrt{p^2+q^2}}{h^2}=RHS$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial s}\left(\frac{pq}{h}\right)+\frac{\partial}{\partial n}\left(\frac{q^2}{h}\right)+2\frac{pq}{hR_s}+\frac{q^2-p^2}{hR_n}+gh\frac{\partial H}{\partial n}+\frac{g}{C^2}\frac{q\sqrt{p^2+q^2}}{h^2}=RHS$$

$$\frac{\partial H}{\partial t}+\frac{\partial p}{\partial s}+\frac{\partial q}{\partial n}-\frac{q}{R_s}+\frac{p}{R_n}=0$$

where
s,n are the coordinates in the curvilinear coordinate system,
p,q are the mass fluxes in the *s* and *n* direction, respectively,
H is the water level,
h is the water depth,
g is the gravitational acceleration,
C is the Chezy roughness coefficient,
R_s and R_d are the radii of curvature of *s*- and *n*-lines, respectively, and
RHS is the right hand side describing all of Reynold stresses.

The general version of MIKE 21 is based on a rectilinear grid for simulations of open sea and coastal applications. However, in river applications an accurate resolution of the boundaries is required which necessitates the use of curvilinear grids. The benefits of using a curvilinear computational grid (MIKE 21C) are visualized in

Figure 1, where a river reach is represented by both grids. The curvilinear grid (MIKE 21C) requires fewer computational points and, thus, smaller storage capacity than the rectilinear grid (MIKE 21), providing at the same time a better resolution of the flow near the boundaries (MIKE 21C, 2011a). Based on this, in order to have an accurate prediction of river flow velocity and flow depth in the study area, the curvilinear computational grid of MIKE 21C was used.

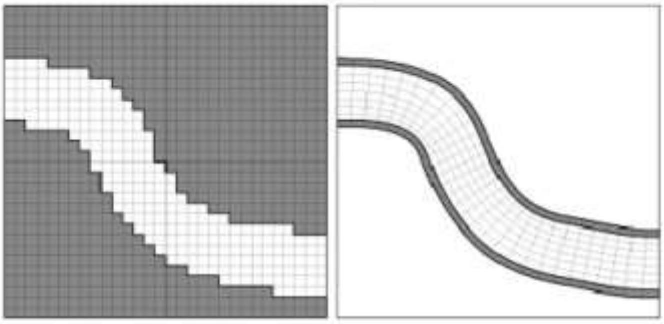

Figure 1: Left: A rectilinear grid (MIKE 21 model). Right: A curvilinear grid (MIKE 21C model), by MIKE 21C, 2011, User Guide

3. MIKE 21C application

3.1. Study Area

The MIKE 21C model was applied to the downstream section of the Koiliaris River Basin, which is located 15 km east of the city of Chania in Crete. The basin extends from the White Mountains (Lefka Ori) to the coastline. The watershed has a total catchment area of 130 km^2 (Figure 2). The total length of the Koiliaris River network is 36 km (Kourgialas *et al*., 2008). From the intersection point, where all the streams meet, to the outflow point the length of the river is 3.3 km (downstream part).

Figure 2: The Koiliaris River Basin.

3.2. MIKE 21C model set-up

The most important process in the MIKE 21C model is the creation a suitable curvilinear grid (De Villiers and Basson, 2007). Thus, a curvilinear grid was created using 6750 cells (Figure 3A). Next, a bathymetry data file of the river bed with only the coordinates and their heights above sea level was created and imported into the grid. The bathymetry of the downstream section of the Koiliaris River is shown in Figure 3B.

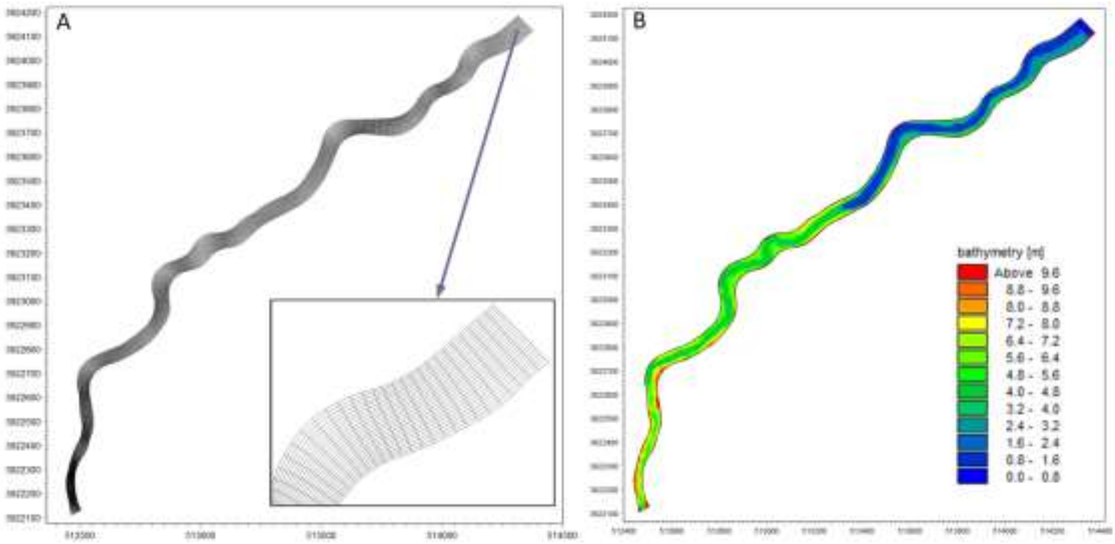

Figure 3: A) The curvilinear grid, B) The bathymetry file.

The MIKE 21C model requires a true land value. All grid points with elevation greater than or equal to the true land value will always be considered as land and will not be subject to possible flow simulation. In this work, the true land value was set equal to 10 m. This value was also s*et al*ong the bank lines in order to allow water inflow and outflow from the open boundaries upstream and downstream only.

Manning’s coefficient (n) was selected as a model calibration parameter along the downstream river reach. The calibration process was performed for the time period 01/10/2010–30/09/2011. The upstream boundary condition which describes the hourly discharge time series in the upstream part of the Koiliaris River was obtained from the hydrometric station of Agios Georgios.

4. Results

The results from MIKE 21C are two-dimensional maps of water depth and flow velocity. The results illustrated in Figures 4A and 4B are for a representative time step (28/02/2011). This time step was selected because it demonstrates the discharge peak of the dataset. The river segments where the velocity vectors are larger are the ones where the river width is small or where the river geometry changes drastically.

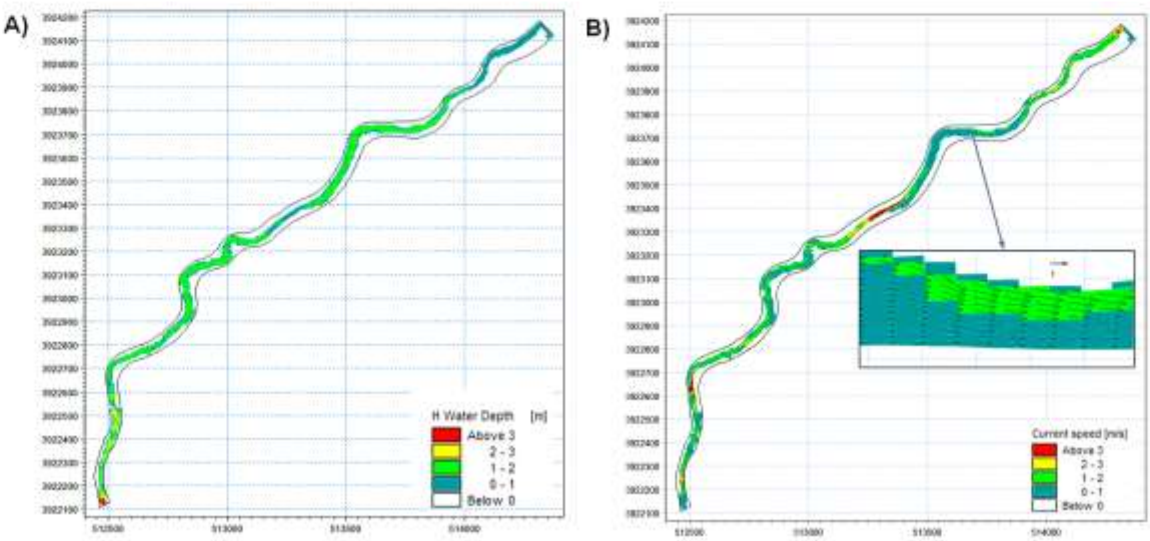

Figure 4: A) The 2D map of water depth, B) 2D map of velocity vectors.

5. Conclusions

The aim of this study was the hydraulic simulation of the flow velocity and flow depth of the Koiliaris River in Crete, Greece. The two-dimensional curvilinear hydraulic model MIKE 21C was employed in order to achieve better resolution of the flow near the boundaries and thereby a higher modeling accuracy. Following the calibration process, the 2D maps of water surface elevation and of flow velocity vectors were produced. By using the MIKE 21C simulation results, the hydraulic and morphological changes of the river can be monitored effectively.

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REFERENCES

1. Danish Hydraulic Institute. 1997. MIKE11 GIS Reference and User Manual. DHI: Horsholm
2. De Villiers, J. and G. Basson (2007), "Modelling of long-term sedimentation at Welbedacht Reservoir, South Africa." Journal of the South African Institution of Civil Engineering **49(4)**: 10
3. Kourgialas, N. N., G. P. Karatzas and N. N. Nikolaidis (2008), Simulation of the flow in the Koiliaris River basin (Greece) using a combination of GIS, the HSPF model and a karstic–snow melt model, International Environmental Modelling and Software Society.
4. Kourgialas, N.N., Karatzas, G.P. (2013), A hydro-economic modelling framework for flood damage estimation and the role of riparian vegetation. Hydrological Processes **27(4),** 515-531.
5. MIKE 21C (2011a). Curvilinear Model for River Morphology, User Guide, DHI Water & Environment.
6. MIKE 21C (2011b). Curvilinear Model, Scientific Documentation, DHI Water & Environment.
7. O'Brien JD. (2006), FLO-2D User's Manual, Version 2006.01. FLO Engineering: Nutrioso.
8. USACE1. 2002. US-Army Crops of Engineers, HEC-River Analysis System, Hydraulic Reference Manual, Version 3.1.