Numerical Limitations of 1D Hydraulic Models Using MIKE11 or HEC-RAS software – Case study of Baraolt River, Romania

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Abstract. MIKE 11 is an advanced hydroinformatic tool, a professional engineering software package for simulation of one-dimensional flows in estuaries, rivers, irrigation systems, channels and other water bodies. MIKE 11 is a 1-dimensional river model. It was developed by DHI Water • Environment • Health, Denmark. The basic computational procedure of HEC-RAS for steady flow is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction and contraction / expansion. The momentum equation may be used in situations where the water surface profile is rapidly varied. These situations include hydraulic jumps, hydraulics of bridges, and evaluating profiles at river confluences. For unsteady flow, HEC-RAS solves the one-dimensional Saint Venant Equation using an implicit, finite difference method. The unsteady flow equations solver was adapted from Dr. Robert L. Barkau’s UNET package. Fluid motion is controlled by the basic principles of conservation of mass, energy and momentum, which form the basis of fluid mechanics and hydraulic engineering. Complex flow situations must be solved using empirical approximations and numerical models, which are approximations of the basic principles (backwater equation, Navier-Stokes equation etc.). All numerical models are required to make some form of approximation to solve these principles, and consequently all have their limitations. The study of hydraulics and fluid mechanics is grounded on the three basic principles of conservation of mass, energy and momentum. Real-life situations are frequently too complex to solve without the aid of numerical models. There is a tendency among some engineers to discard the basic principles taught at university and blindly assume that the results produced by the model are correct. Regardless of the complexity of models and despite the claims of their developers, all numerical models are required to make approximations. These may be related to geometric limitations, numerical simplification, or the use of empirical correlations. Some are obvious: one-dimensional models must average properties over the two remaining directions. It is the less obvious and poorly advertised approximations that pose the greatest threat to the novice user. Some of these, such as the inability of one-dimensional unsteady models to simulate supercritical flow can cause significant inaccuracy in the model predictions.

1. Introduction
Investigated area is Baraolt area, surrounded by mountains on the right bank Harghita respectively Baraolt Mountains in the left bank.
In the area between Biborțeni and Baraolt, p Baraolt has a minor channel openings 8 to 25 m (in some erosion cuvettes touch 70 to 75 m) lower in town Baraolt (ca. 6 to 8 m), respectively downstream in
some areas where the distance between the sides is reduced from 4 to 5 m. The plan view is presented in Figure 1.

Figure 1. Plan view

The banks are generally asymmetric (except in designated areas inside or outside the village Baraolt) generally steep and variable heights between 1.50 and 2.00 m and height sometimes still natural bank collapses because they have affected. Baraolt creek in some areas is decorated with gabions, pitching built concrete parapets concrete revetment slabs concrete embankment.

Floodplain has extensions ranging approximately between 100 - 1300 m The slopes of the two sides formed pre-Holocene formations are asymmetric:
- slope as steeply somewhat smoother and continuity;
- left side shows steep slopes is less fragmented in the meeting of the landslide and the base to limit the accumulation meadow and ponds, ponds with vegetation hydrophilic from runoff and underground springs.

Shares in the land near banks are summarized approximately 493 mdMN upstream and 464 mdMN downstream. Baraolt is right tributary stream of Olt River, flowing in a NE - SW, has a marked sinuous meanders, dead arms, Disintegrating thresholds submerged, variations in the flow section and the following characteristics river:
- a length of 40 km;
- a basin area of 121 km²;
- an average slope of 22 ‰;
- a tortuosity coefficient of 1.17.

The stream has a high flow rate, force erosion and very high rate of solid transport. In some areas of minor riverbed is, due to erosion and alluvial erosion, funnel is created true major diameter over 50 - 60 m.

During the year between Biborţeni and Baraolt, stream receives several courses, leaking rain upstream and generally in areas where the stream based approach slopes.

Hydro surface consists of coarse silt bed and major groundwater was mainly of free level or slightly ascending. Hydrostatic level of groundwater is influenced by rainfall, the relationship that exists between aquifer hydraulic floodplain coarse of geomorphological units and adjacent aquifers - deluvial, proluvial and colluvium, terrace - on the one hand, and the relationship established with the main drainer of hydraulic area - p Baraolt.
Groundwater level was encountered generally 2.50 to 4.00 m depth. There are areas in which a hydrogeological relationship with volcanogenic sedimentary bedrock aquifers and groundwater debited under pressure with a high mineral content and CO₂.

This area has a sinuous river Baraolt marked by numerous bends of varying degrees of openness, submerged sills, meanders, arms, dead (magnitude and higher frequency near the confluence with river Olt where floods and prolongs its remuneration lead to training material saturated with low mechanical strength of the sides), variations in the geometry and flow rate, ramble, Disentangling [3].

2. Material and methods

Computational fluid dynamics can be defined as a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyse problems involving fluid flows. The term “CFD model” is commonly used to refer to a high-order numerical model capable of solving complex fluid situations with relatively few simplifications.

In reality, all numerical models are CFD models (even a simple spreadsheet solution of the backwater equation). There are generally considered to be two methods of analysing fluid motion: by describing the detailed flow pattern at every point in the flow field (small scale or differential analysis), or by examining a finite region and determining the gross effects of and on the region (finite or control-volume analysis).

The complexity of real fluid flow makes it impossible to solve the governing equations without making some form of simplifying approximation, even with the use of complex models and fast computers. Common practices include: simplification of the spatial and geometric properties, assumption of steady or quasi-steady flow conditions, neglect of fluid properties that would have negligible influence in the circumstances being investigated, and use of empirical formulae to approximate flow characteristics [1].

The basic computational procedure of HEC-RAS for steady flow is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction and contraction / expansion. The momentum equation may be used in situations where the water surface profile is rapidly varied. These situations include hydraulic jumps, hydraulics of bridges, and evaluating profiles at river confluences.

For unsteady flow, HEC-RAS solves the full, dynamic, 1-D Saint Venant Equation using an implicit, finite difference method. The unsteady flow equation solver was adapted from Dr. Robert L. Barkau’s UNET package.

Hydraulic models may be characterized by the spatial and temporal simplifications that the model employs. Each category has associated with it a number of fluid properties and dynamic assumptions.

A less obvious simplification common to many numerical models (HEC-RAS, MIKE 11) is to assume that the grade of the channel is small, nominally less than 1:10, and therefore the sine and cosine of the channel slope can be assumed equal to zero and unity respectively.

HEC-RAS is equipped to model a network of channels, a dendritic system or a single river reach. Certain simplifications may be made in order to model some complex flow situations using the HEC-RAS one-dimensional approach capable of modelling subcritical, supercritical, and mixed flow regime flow along with the effects of bridges, culverts, weirs, and structures.

HEC-RAS is a computer program for modelling water flowing through systems of open channels and computing water-surface profiles. HEC-RAS finds a particular commercial application in floodplain management and flood insurance studies to evaluate floodway encroachments. Some of the additional features include: bridge and culvert design and analysis, levee studies, and channel modification studies. It can be used for dam breach analysis, though other modelling methods are presently more widely accepted for this purpose.

HEC-RAS has merits, notably its support by the US Army Corps of Engineers, the future enhancements in progress, and its acceptance by many government agencies and private firms. It is in the public domain and peer-reviewed. The use of HEC-RAS includes extensive documentation, and scientists and engineers versed in hydraulic analysis should have little difficulty utilizing the software.

Users may find numerical instability problems during unsteady analyses, especially in steep and/or highly dynamic rivers and streams. It is often possible to use HEC-RAS to overcome instability issues
on river problems. HEC-RAS is a 1-dimensional hydrodynamic model and will therefore not work well in environments that require multi-dimensional modelling. However, there are built-in features that can be used to approximate multi-dimensional hydraulics [5].

MIKE 11 is an advanced hydroinformatic tool, a professional engineering software package for simulation of one-dimensional flows in estuaries, rivers, irrigation systems, channels and other water bodies. MIKE 11 is a professional engineering software package for the simulation of flows, water quality and sediment transport in estuaries, rivers, irrigation systems, channels and other water bodies. MIKE 11 is a user-friendly, fully dynamic, one-dimensional modelling tool for the detailed analysis, design, management and operation of both simple and complex river and channel systems. With its exceptional flexibility, speed and user friendly environment, MIKE 11 provides a complete and effective design environment for engineering, water resources, water quality management and environmental applications.

The Hydrodynamic (HD) module is the nucleus of the MIKE 11 modelling system and forms the basis for most modules including Flood Forecasting, Advection-Dispersion, Water Quality and Non-cohesive sediment transport modules. The MIKE 11 HD module solves the vertically integrated equations for the conservation of continuity and momentum, i.e. the Saint Venant equations.

The MIKE 11 is an implicit finite difference model for one dimensional unsteady flow computation and can be applied to looped networks and quasi two-dimensional flow simulation at floodplains. The model has been designed to perform detailed modelling of rivers, including specialist treatment of floodplains, road overtopping, culverts, gate openings and weirs. MIKE 11 is capable of using kinematic, diffusive or fully dynamic, vertically integrated mass and momentum equations. Boundary types include Q-h relation, water level, discharge, wind field, dam break, and resistance factor. The water level boundary must be applied to either the upstream or downstream boundary condition in the model. The discharge boundary can be applied to either the upstream or downstream boundary condition, and can also be applied to the side tributary flow (lateral inflow). The lateral inflow is used to depict runoff. The Q-h relation boundary can only be applied to the downstream boundary. MIKE 11 is a modelling package for the simulation of surface runoff flow, sediment transport, and water quality in rivers, channels, estuaries, and floodplains. The computational core of MIKE 11 is hydrodynamic simulation engine, and this is complemented by a wide range of additional modules and extensions covering almost all conceivable aspects of river modelling.

Fluid motion is controlled by three basic principles: conservation of mass, energy and momentum. Derivatives of these principles are commonly known as the continuity, energy and momentum equations. These principles are among the first taught in basic fluid mechanics, and they form the foundation of the field of hydraulic engineering. However, as situations become increasingly complex, we lose track of these essential principles. Basic equations are replaced by empirical approximations, and mathematical calculations with numerical models. Determining an equivalent surface roughness of a floodplain is far more difficult than estimating an equivalent roughness height or a Manning’s roughness coefficient; solving a backwater equation for an irregular channel would be an arduous task without the assistance of a numerical model.

Numerical models come in a wide range of shapes and flavours – one, two or three dimensions, steady or unsteady flow conditions etc. All are based on derivations of the basic principles. All are required to make some form of numerical approximation to solve these principles. All have their limitations.

The objective of this paper is to promote a basic awareness of how numerical models operate and to draw attention to some of the more common limitations that are implicit to this operation, in the hope that this may encourage these models to be used in (and only in) the manner for which they are intended.

3. Results and discussions

To exemplify of numerical modelling with MIKE 11 and HEC-RAS hydroinformatic tools was considered a sector of Baraolt River, located in central Romania. The considered sector has a length of 11 km; representative cross sections are considered between Baraolt and Olt River confluence (Figure 1). Cross sections have been raised by the Romanian Waters, Olt, Water Basin Administration.
The input data are: area plan with location of cross sections (Figure 2); cross sections topographical data and roughness of river bed (Figure 3); flood discharge 1%, 2%, 5% and 10% in section 79 [2] and Bridge culvert data in cross section 9.2, 23.2, 28.2, 30.2, 40.2, 42.2 and 45.2. After simulation with software MIKE11 and HEC-RAS, a longitudinal profile was obtained, presenting water levels along the river (Figure 4).

Figure 2. Plan view with network model MIKE11 and HEC-RAS

Figure 3. Cross sections (for example cross sections 1, 10, 20, 30, 40, 50, 60, 70, 79) MIKE11 and HEC-RAS
Figure 4. Longitudinal profile

Main Channel  Distance (m)

Elevation (m)

Legend

EG  1 %

WS  1 %

EG  2 %

WS  2 %

EG  5 %

WS  5 %

EG  10 %

WS  10 %

Crit  1 %

Crit  2 %

Crit  5 %

Crit  10 %

Ground

Left Levee

Right Levee

Retracted
4. Conclusions

Numerical models usually solve the backwater equation between adjacent cross-sections using an iterative procedure called the standard step method. The primary assumption of the integrated backwater equation used in steady-state numerical modelling is that the flow is gradually varied (Henderson, 1966). This implies that changes along the channel, such as cross-section shape, invert level, flow depth, and pressure distribution, are relatively small over short distances.

The backwater equation has questionable or no accuracy in: areas of rapid acceleration or deceleration, where the assumption of a hydrostatic pressure distribution is no longer valid, areas of large turbulence and/or energy loss, and areas of large change in cross-section property where the assumption that the representative friction slope and contraction/expansion losses can be estimated by some combination of the section properties at each end. While the backwater equation is based on a steady-state differential form of the Energy equation, the Saint Venant equation based solutions can model unsteady flow conditions.

Many software packages, including HEC-RAS and MIKE 11, adopt an algorithm that cannot accommodate two boundary conditions at the same boundary. As a consequence, they cannot model supercritical flow, for which both, discharge and water level, are controlled by the upstream boundary. Instead, supercritical flow conditions are ‘solved’ by suppressing the convective acceleration as the Froude number increases.

The study of hydraulics and fluid mechanics is founded on the three basic principles of conservation of mass, energy and momentum. Real-life situations are frequently too complex to solve without the aid of numerical models. There is a tendency among some engineers to discard the basic principles taught at university and blindly assume that the results produced by the models are correct. Regardless of the complexity of models and despite the claims of their developers, all numerical models are required to make approximations. These may be related to geometric limitations, numerical simplification, or the use of empirical correlations. Some are obvious: one-dimensional models must average properties over the two remaining directions. It is the less obvious and poorly advertised approximations that pose the greatest threat to the novice user. Some of these, such as the inability of one-dimensional unsteady models to simulate supercritical flow, can cause significant inaccuracy in the model predictions.

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