Hydraulic Engineering Software VIII, C.A. Brebbia & W.R. Blain (Editors)
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Comparison of the software packages ISIS and Mike11 for the simulation of open channel flow

R. Van Looveren[1], P. Willems[2], M. Sas[1],
C. Bogliotti[3] & J. Berlamont[2]
[1]*IMDC nv, Belgium.*
[2]*Laboratorium voor Hydraulica, K.U.Leuven, Belgium.*
[3]*Hydrodata-IC bvba, Belgium.*

Abstract

In this study two well known commercial software packages for one-dimensional open channel flow are compared to each other: ISIS from HR Wallingford and Mike11 from the Danish Hydraulic Institute (DHI). The comparison is confined to the two most important modules, namely the hydrodynamic and the hydrological module. It is proven that the hydrodynamic parts of ISIS and Mike11 are very similar. They are both found on the same physical equations (de Saint Venant) and the difference in solution algorithms only leads to local differences in the results (e.g. at hydraulic jumps). ISIS and Mike11 take however a different view on how hydraulic structures are to be modelled. The differences between both packages are more pronounced for the hydrological modules and when the user friendliness is regarded. Finally both packages are compared to each other on the basis of a practical example, namely on the Dijle river in Belgium.

1 Introduction

As requested by the Water Division of the Ministry of the Flemish Community (departement Leefmilieu en Infrastructuur, AMINAL, afdeling Water), two commercial software packages for 1-dimensional open channel flow were compared to each other: Mike11 from the Danish Hydraulic Institute (DHI) and ISIS from HR Wallingford. To do this, the most recent PC versions that were then available, i.e. version 4.01 for Mike11 and version 1.3 for ISIS, were used.

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The comparison consisted of a theoretical and a practical part. The theoretical part will be described first, at the end of the paper the practical comparison is described briefly.

The theoretical evaluation is based on three criteria sets: the technical criteria, the user friendliness and the presentation- and postprocessing possibilities.

1. In the technical criteria the different modelling concepts and technical possibilities from both packages are described. On what principles are the calculation methods based? Which hydraulic structures, initial- and boundary conditions can be imposed? Are there limitations on the amount of input data or indirect limitations that are caused by the large simulation time?
2. For the user friendliness it is of special importance to appreciate how easy it is to enter input data into the packages, to edit or delete this data afterwards and how a numerical model is built structurally. Also the presence of clear and exhaustive manuals (possibly on-line), the availability of default values and apposite and clear warnings is important.
3. Finally, both packages can differ in the way they present their results (tabularly, graphically, ...), and in the possibilities they offer to calculate additional variables and to process the results statistically. This is described under presentation- and postprocessing possibilities.

In this paper only the technical criteria and the user friendliness are described, as they are considered to be the most important.

Both software packages have a modular structure. Modules are available for hydrodynamic and the hydrological calculations, for the simulation of water quality, sediment transport, etc. Within the frame of this study, only the hydrodynamic and hydrological modules were compared. The other modules were only briefly reported on. In the following text, the distinction between the different modules will be discussed only in the description of the technical criteria. As all modules are integrated in total packages, they do not show any differences regarding user friendliness and presentation possibilities.

2 Technical criteria

2.1 The hydrodynamic module

2.1.1 Calculation methods applied

Both programmes solve exactly the same physical equations, namely the one-dimensional equations of de Saint Venant. These equations express the conservation of mass and the conservation of momentum on the basis of a number of assumptions and simplifications, of which the most important are: 'the water is incompressible' and 'the flow everywhere can be regarded as having a direction parallel to the bottom'.

In both packages these equations are solved using the method of finite differences. The solution is obtained in a number of discrete points (with distance interval Δx) and for a number of discrete times (with time step Δt) for which derivatives are approximated by their finite differences. Both packages differ in

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the way they approximate the derivatives by finite differences resulting in two other finite difference schemes: the 4-point Preissmann scheme in ISIS and the 6-point Abbott-Ionescu scheme in Mike11. Both schemes have similarities and dissimilarities.

The most remarkable dissimilarity is that in the Preissmann scheme water level and discharge are calculated at the same discretisation point, whereas the Abbott-Ionescu scheme consists of alternating discretisation points where water level (h-point) and discharge (Q-point) are calculated respectively. The practical difficulties, that could arise from this staggered computational grid, in defining hydraulic structures and boundary conditions, are completely taken care of by Mike11 internally, so that the user isn't troubled by this.

The most remarkable similarity between both schemes is that they are implicit, meaning that, at each time step, the new values of water level and discharge at a certain discretisation point can only be determined if the equations at all discretisation points are solved at once. Studies ([1], [7], [8]) have proven that this type of difference scheme has better stability characteristics than their counterparts, the so-called explicit schemes, where the new value of water level and discharge at a certain discretisation point can be found by only solving the equations in a number of adjacent points (a calculation is called stable if a small error, like for instance truncation errors, stay small during the whole computation).

Both schemes can however lead to different results locally. This occurs for instance, in the simple steady flow computation in a prismatic channel when a transition takes place from supercritical to subcritical flow (a hydraulic jump). Figure 1 compares, for this case, the results of ISIS and Mike11 with the results of the numerical integration while simultaneously solving the equation of Bélanger [2]. The figure shows that ISIS nor Mike11 can represent this discontinuous transition exactly. This is logical, since the assumptions that are the basis of the equations of de Saint Venant are not valid anymore in the vicinity of the hydraulic jump. The discontinuity is 'smoothed out' over the neighbouring discretisation points. Mike11 deviates from the numerical computation with a simultaneous solution of the equation of Bélanger, upstream and downstream of the hydraulic jump. These deviations are smaller in ISIS and are situated predominantly upstream the jump.

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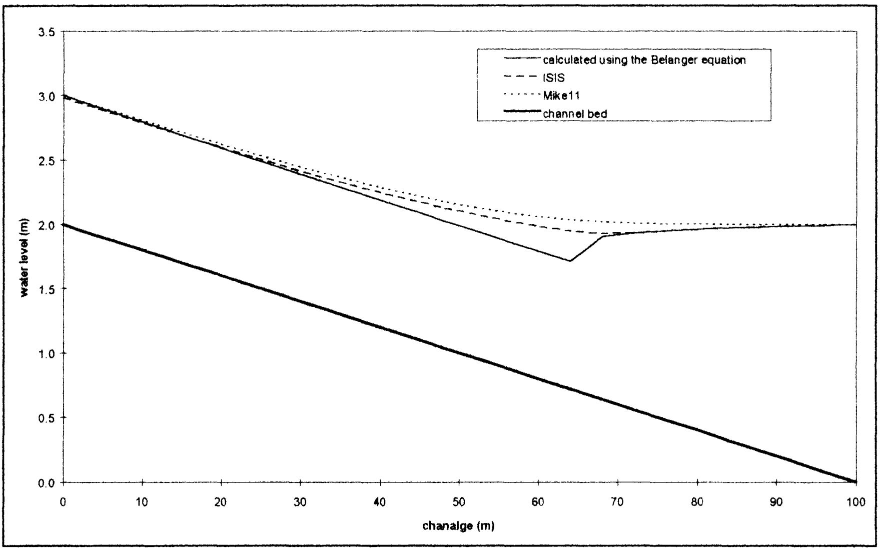

Figure 1: Transition from subcritical to supercritical flow through an hydraulic jump in a prismatic channel.

However, generally speaking one can say that the discretisation method applied has only small influence on the results.

The equations of de Saint Venant are with the method of the finite differences transformed to a system of algebraic equations that can be solved numerically. The algorithm used to solve this system differs for both packages. Mike11 uses a 'double sweep' algorithm and ISIS a variation on the Gaussian method. It is not expected that this difference in solution algorithm leads to differences in the simulation results [7].

2.1.2 The hydraulic structures

ISIS as well as Mike11, can incorporate a large number of structures. Although almost all important structures can be modelled in both packages, two significant conceptual differences can be noted.

1. ISIS offers a specific unit for almost all hydraulic structures that can possibly occur in practice: units exist for different kinds of weirs, a siphon, a vertical sluice, a radial sluice, different bridge types, a culvert, an orifice, a pump etc. In Mike11, all possible hydraulic structures must be 'reduced' to four basic units: a weir, a sluice, a culvert and a regulating structure. These four basic units are however, versatile and flexible, so that almost all hydraulic structures can be modelled using one of these basic units. A bridge, for instance, can be modelled as a culvert. Modelling with these versatile units anticipates the user to have experience and inventivieess.

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2. The equations in ISIS for the hydraulic structures are based mostly on empirical measurements (in laboratories and in the field). The USBPR Bridge unit for instance to model bridges, is based on a study carried out by the US Bureau of Public Roads during which a large number of measurements were taken concerning the backwater effect caused by bridges and scale models of bridges from the United States. As such empirical relations could be formulated between the backwater effect, the discharge and a number of geometrical characteristics of the bridge (ratio of bridge opening area to area of unimpeded section, number and shape of the piers, abutment type, ...). Other ISIS units are also based on empirical relations, like the definition of head losses in a culvert, the discharge coefficient and the modular limit of a weir and a sluice, ... For these structures the user has to enter a number of (directly measurable) physical characteristics and the software itself computes the necessary (loss) coefficients.

   The equations in Mike11 for the hydraulic structures are all variations of the Bernoulli equation applied between a point upstream and a point downstream of the structure and incorporates the entrance, exit and additional head loss. The values of these loss coefficients must be entered by the user directly. Experience is required for the determination of these values.

Apart from these two major conceptual differences, certain hydraulic structures have been implemented differently in both packages: the lateral spill, the reservoir and the culvert.

2.1.3 Initial and boundary conditions / hydraulic roughness

The main difference between the packages in defining the boundary and initial conditions is that Mike11 uses an absolute time axis, while ISIS uses a relative time axis. In an absolute time axis the full date is shown (year, month, day, hour, minutes, seconds). The relative time axis only shows the number of time units (e.g. hours or days) that have passed since an arbitrarily chosen starting point (e.g. the start of a rainfall event).

In ISIS as well as in Mike11, the hydraulic roughness can vary over the cross-section (for instance, to account for the differences in roughness in the bed and on the banks) and along a longitudinal profile. Only Mike11 allows for the variation of the roughness as a function of time (e.g. seasonal variations as a result of plant growth).

2.1.4 Limits on the input data / simulation time

Experience shows that many applications have difficulties when they have to deal with a large amount of data. It can however, be very useful to work with a large amount of data, for instance when the historical rainfall data of a number of years has to be calculated (in combination with a continuous hydrological model, cf. §2.2) or if one wants to model a large catchment in great detail.

In order to test this, extensive (fictitious) time series and cross sections were defined and imported into both software packages.

The number of calculation points (and, consequently, the number of cross-sections, structures, ...) in ISIS is licence dependent. A licence exists for 50, 250, 1000 and 2000 calculation points. The Mike11 licences have no limitation on the number of calculation points. During the tests up to 10.000 calculation points were inserted in Mike11, without causing any problem.

The number of values in a input series in ISIS is limited to approximately 5000 and the number of values in a result series upto approximately 8000. The values in a input series are for instance, hourly rainfall data, daily water level data, etc. Their number and frequency is determined by the availability of measurements. The values in a result series constitute the output of a numerical simulation. Their number and frequency is determined by the simulation period and the save interval. The number of values in a input series can, in some cases, be reduced. The rainfall records of dry weather periods for instance, do not need to be kept in the database. The value of the save interval however, cannot vary between a rainfall period and a dry weather period. Consequently, if one wants to do an ISIS simulation with an hourly save interval, the simulation period will be limited to approximately 330 days. In Mike11, time series can be introduced and result series can be produced upto 1.000.000 values. The number of values in a time series is unlimited.

When simulating a long time series and/or a detailed model of a large catchment, it is not only important that the software package can handle this large amount of data, but also that the time required for the simulation is in acceptable limits. In spite of the increasing speed of modern CPU's, the large simulation time still hinders the simple use of the packages and in some cases, for instance for real-time forecasts, it is even a limiting factor. To test the calculation speed, the simulation time of a number of model set-ups was measured. These tests were carried out for small models (with a small amount of calculation points) as well as for more complex models. From the results, it appears that Mike11 is approximately 2 times faster for a complex model and 3 times for the smaller models.

The previous description already shows clearly that Mike11 has been traditionally used to perform long (continuous) simulations (Mike11 uses an absolute time axis and the database can handle a large amount of data), whereas ISIS is more event based and has to simulate each rainfall event separately. This conclusion is confirmed by the choice both packages have made for their hydrological modules.

2.2 The hydrological module

The hydrodynamic parts of ISIS and Mike11 are based on the same principles (both packages use the equations of de Saint Venant). This is not the case for the hydrological part, for which the packages use quiet different methods.

ISIS has implemented the S.C.S. (Soil Conservation Service) and the F.S.R. (Flood Studies Report) methods [12]. Mike11 [11] offers the choice between the same S.C.S. method and the model NAM.

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All these models are conceptual. This means that they are based on a simplified representation of the rainfall runoff process, in which the relation between input and output of the model is based on semi-empirical equations. The physical meaning of the parameters that the models use for the description of the hydrological process is therefor insufficient, to be able to determine their values directly from measurements. The parameter values are mainly obtained by calibration. Additionally, all these models are lumped. The value of a certain parameter is fixed for the entire catchment (or subcatchment) and, consequently, does not account for the spatial variation of the catchment characteristics.

The methods that ISIS and Mike11 use, describe the rainfall runoff process in a more detailed manner than the so-called blackbox models, in which the parameters applied have no physical meaning at all, but they are less detailed than the physically based spatially distributed models.

The major difference between both packages is that ISIS offers only discontinuous conceptual models, whereas the Mike11 NAM model is continuous.

The discontinuous models (S.C.S. and F.S.R.) can be used to simulate separate rainfall events. They calculate surface runoff from the precipitation rate taking into account a very simplified method for representing losses (initial and/or proportional losses). These methods start from the assumption that the hydrological 'system' is linear and time independent (in other words, that the same rainfall event causes the same surface runoff at any time). These methods are very appropriate if little data is available. Calibration is quite easily done.

The continuous model NAM is used to simulate long historical time series. Because baseflow and interflow are also modelled (apart from the surface runoff), this type of model can also be used for dry weather periods. Additionally, the same rainfall event will produce lower runoff in summer (when soil is dry) than in winter (on wet soil). Consequently, continuous models generally give more accurate results than discontinuous models, provided however that sufficient data is available to carry out good calibration.

2.3 Other modules

Apart from the two basic modules (the hydrological and the hydrodynamic module) both producers offer a large number of other modules as well. Only the most important ones are mentioned:

- a module for the non-cohesive sedimenttransport
- a module for advection-dispersion and for water quality
- the dambreak module

The possibilities of these 'add-on' modules are equivalent in both packages.

2.4 Linking with other models

Now that the concept of integrated water management grows in importance, it is of relevance that linking of river models with other models is also developed. A link between Mike11 and Mouse (the sewerage system model of DHI) is already available. The sewerage system and the river system can interfere with each other in two directions (overflow from the sewerage system to the watercourse, backwater flow from the watercourse in the sewerage system). HR Wallingford also confirmed that developments for a similar integration are in progress. Additionally, DHI is planning to build a link between Mike11 and MikeSHE (the groundwater model).

3 The userfriendliness

Regarding the user friendliness, both packages have three major differences:

1. differences in the file structure.
2. differences in the Graphical User Interface (GUI)
3. differences in the manuals

In ISIS all data regarding a particular simulation are stored in one and the same datafile. This file contains the cross-sectional geometry, the data regarding the hydraulic structures, the boundary conditions, certain simulation parameters etc. The advantage of this approach is that no confusion can arise about which data was used in which simulation, but the approach has disadvantages as well. If for instance, one wants to simulate the same river network for x different rainfall events, one has to create x different datafiles, that however, contain largely the same information (cross-sections, structures, ...). If, subsequently, one discovers an error in this river network, one has to correct it x times.

The file structure of Mike11 is more complex, but for large modelling studies this is beneficial. The package uses two types of database. The first type contains all time series (e.g. of water levels, discharges, precipitation, salinity,...), the second type contains the cross-sectional geometry. These two database types can hold more data than is necessary for one simulation. The time series database for instance, can contain data of a large number of rainfall events measured at a large number of stations. The cross-sectional database can contain for instance, cross-sectional data of a river branch before and after relining. Which data are used where and when in a particular simulation, is described in two additional files, the so-called editors: the network editor for the cross-section database and the boundary editor for the time series database. Besides these two 'basic' editors, other editors exist where the user can enter values for the parameters that are specific for a certain module (rainfall-runoff parameters, dispersion coefficients, ...). Finally, the simulation editor gathers all filenames of a simulation. This approach demands some discipline from the user (for defining filenames,...), but has the important advantage that all data is stored only once, so when an error is detected, it also has to be corrected only once.

The GUI of ISIS is partly Windows-based and partly DOS-based. It is for instance, possible to handle a large part of the program using the mouse and toolbottons, but almost all data is inserted via a DOS-based editor. The consequence is that it is not possible to directly import or export from or to other

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Windows applications (Word, Excel). The input data cannot be directly controlled graphically for errors.

The new Mike11 version uses a GUI that is completely integrated in the Windows95 environment. This interface uses the same standards for the menus, toolbuttons, dialogue boxes etc., as other Windows applications. Eventually, all DHI software will have a similar GUI (for the sewerage system package Mouse, this has already been realised). Through this GUI it is possible to directly exchange data with other Windows applications and inserted data can immediately be graphically controlled and corrected.

The ISIS manual is more user oriented and also describes briefly the equations and methods applied. The Mike11 manuals go more deeply into the theory behind these equations and methods and into the way they are implemented in the numerical scheme. The manuals are however, those of the previous Mike11 version, that had a totally different user interface. Consequently, the manuals are quite difficult to read. To compensate this in some way a short introduction is included with the new version. This introduction does not highlight however, all the topics.

4 Practical comparison

Finally both packages were compared to each other on the basis of a practical example, namely the watershed of the Dijle river upstream of the city of Leuven (Belgium). An existing ISIS model of this catchment was converted to an equivalent Mike11 model by a systematic procedure for the conversion. Two types of conversion have been made: a conversion where the Mike11 model was calibrated to the ISIS model, i.e. the parameter values are defined in such a way that the influence of each hydraulic structure on the river flow is almost identical in Mike11 as in ISIS (type I) and a conversion where default parameter values were used in Mike11 (type II), the default values are indeed most often chosen as parameter values by an independent Mike11 modeller. For a detailed description of this comparison the reader is referred to [15] and [17].

Generally one can conclude that large experience with the modelling package and the river cathment and also insight in the real behaviour of hydraulic structures are much more important than the choice one has to make between the modelling packages ISIS and Mike11. The accurate estimation of model parameter values (different from the default values) can be very important for the accuracy of the model results.

5 Conclusion and future developments

The hydrodynamic parts of ISIS and Mike11 are very similar. They are both founded on the same physical equations (de Saint Venant) and the difference in solution algorithms only leads to local differences in the results (e.g. at a hydraulic jump). ISIS and Mike11 take however, a different view on how hydraulic structures are to be modelled. ISIS offers for each structure type a specific unit.

The head loss in these structures is determined on the basis of semi-empirical equations. In Mike11 the user has to 'reduce' the different structure types to a limited number of 'basic' units, in which the head losses have to be determined by the user. Also the practical comparison on the Dijle river in Belgium has proven that the differences in results between both packages are small, taking into account all uncertainties that enter into a modelling application: model input, topological discretisation, parameter estimation etc.

The differences between both packages are more pronounced for the hydrological modules. In ISIS only discontinuous models are available; Mike11 makes use of a more detailed continuous model (NAM).

Finally, there is an important difference in user friendliness. The user friendliness is mainly effected by the file structure and the user interface: ISIS stores all input data in the same file, whereas Mike11 uses a separate file for each data type. The user interface of Mike11 is completely integrated in the Windows environment; the ISIS interface is still partly DOS based.

To conclude this article, the authors would like to stress that the foregoing description is only a snapshot in time, since both packages are continuously evolving and being improved. Meanwhile, both producers have already released a new version of their software package (ISIS v1.4 and Mike11 v4.10) and it appears that both packages have grown towards one another. The new Mike11 version, for instance, allows for the presentation of water levels in a cross-section and for the statistical comparison of calculated and measured data. The new ISIS version uses an improved method to store the processed data of a cross-section (similar to Mike11) and Preissmannslots can be automatically added. It could be expected that both packages will continu growing towards one another in future. HR Wallingford has announced that the next ISIS version will be completely integrated in the Windows environment and will have a continuous hydrological model with it. DHI, for its part, plans the introduction of units to model certain structure types specifically (bridges, additional head loss, ...).

6 Acknowledgements

The authors would like to thank the Flemish authority AMINAL – division Water for the opportunities they have given and for the many critical remarks which have improved the quality of this work to a large extent. The full report of this study can be ordered from them.

References

[1] Abbott M.B., Computational Hydraulics. Elements of the Theory of Free Surface Flows, Pitman, 1979.
[2] Berlamont J., Theorie van de verhanglijnen, Wouters, 1993
[3] Berlamont J., Rioleringen, acco leuven, 1980

[4] Buyst L. and A. Bultheel, Inleiding tot de numerieke wiskunde, eerste deel, VTK, 1987

[5] Bradley Joseph N., Hydraulics of Bridge Waterways, US Federal Highway Administration, 1978.

[6] Richard A. Crowder, Y. Chen, R.A. Falconer, Benchmarking and Scoping Study of Hydraulic River Models - Stage Two - Final Report, Environment Agency, 1997.

[7] Cunge J.A., F.M. Holly, Jr A. Verwey, Practical Aspects of Computational River Hydraulics, Pitman, 1980.

[8] Cunge J.A., On the subject of a flood propagation method (Muskingum method), J. Hydraulics Research, International Association of Hydraulics Research, 1969.

[9] Danish Hydraulic Institute, Mike11 Version 3.12 General Reference Manual, 1995.

[10] Danish Hydraulic Institute, Mike11 Version 4.0 Short Description, 1997.

[11] Danish Hydraulic Institute, NAM Documentation and User's Guide, 1990.

[12] Halcrow/HR wallingford, ISIS Flow User Manual, 1997.

[13] Halcrow/HR Wallingford, ISIS Version 1.3 Release Notes, 1997.

[14] Hydraulics Research Wallingford, Afflux at Arch Bridges, 1988.

[15] TECHNUM/HYDRODATA-IC, Surface water quantity modelling of the Dijle catchment upstream of Leuven with the software package Mike11 and comparison with the ISIS results, 1999.

[16] Ven Te Chow, David R. Maidment, Larry W. Mays, Applied Hydrology, McGraw-Hill International Editions, 1988.

[17] Willems P., Van Looveren R., Sas M., Bogliotti C., Berlamont J., Practical comparison of the modelling systems Mike11 and ISIS for hydrodynamic modelling in the Flemish river Dijle catchment, submitted to Hydroinformatics 2000, Iowa.