SIC 3.0, a simulation model for canal automation design

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INTRODUCTION

The SIC software (Simulation of Irrigation Canals) is one of the latest hydraulic models developed by Cemagref. The first developments on hydraulic numerical modeling started at Cemagref in the early 1970's. Lots of improved and updated versions have been made since this period. Right now, several hydraulic models exist at Cemagref, depending on the type of systems and events to simulate (rivers, irrigation canals, dam break, drainage systems, etc.).

One of these models has been particularly dedicated to irrigation canals. This model, called SIC, has been adapted from another hydraulic model, where some features have been removed, new ones have been introduced, and for which special user-friendly interfaces have been developed. It was also adapted to run on currently available IBM PC computers or compatibles. It can be used both by engineers and by canal managers.

The very first version of this model has been developed for the I.I.M.I. (International Irrigation Management Institute) on a real canal located in the south coast of Sri Lanka (Kirindi Oya Right Bank Main Canal). One purpose of this model was to be easily usable by canal managers as a decision support tool, in order to help them in the daily operation and maintenance of their system.

Since this first application was promising, Cemagref, with other partners, decided to develop a new standard version of this software, that could be used on most of the irrigation canals world-wide.

A Study Advisory Committee has been set up to decide the required features of the model, and follow its development. This Committee led to the SIC User's Club with representatives of the different partners: BCEOM, CACG, Cemagref, CNABRL, ENGREF, IIMI, LAAS, LHF, MAE, MRE, MCoop., OIE, SCP and SOGREAH (Cf. Annex 1 for acronyms). One main purpose of this Club was also to foster communication among model developers and users. It allows to share experiences, new developments, needs of improvements, etc.

The SIC model has been developed at the Irrigation Division of Cemagref Montpellier (France). This division is in charge of commercial and maintenance aspects on the SIC model. Other hydraulic models are still being developed at the Hydraulic Division in Cemagref Lyon, while the Irrigation Division in Montpellier is now focusing on the design of Canal or River regulation techniques, including automatic control techniques.

TECHNICAL MERIT

Computational Accuracy

The SIC hydraulic model is solving the complete Saint Venant equations. It uses the classical implicit Preissmann scheme. The implicit coefficient θ is set to 0.6. The time step can be selected from 0.01 to 999.99 minutes (default value is 10 minutes). The distance step can be chosen by the user (default value is 200 meters).

Different studies have been carried out to study the computational accuracy of the SIC model (or of previous versions). It is impossible to synthesize this accuracy issue in a few general words, since it depends on the type of modeled system, on its size, on the simulated hydraulic conditions, on the number of data entered, on their precision, etc. Nevertheless, evaluation and comparison with other models can be carried out through tests on one or several defined systems and scenarios.

Numerical Solution Criteria

In order to have an idea on the computational accuracy of the model, and to compare different models, the two tests of the ASCE bench marks [1] have been carried out on the SIC model.

Mass Conservation Test

The simulation was made on the SIC 2.1 version with the usual parameters: $\theta = 0.6$ and no iterations. They will be run again on the new 3.0 Windows version. It is expected to lead to even better performance, since this new version is allowed to make iterations.

If the results are given in centimeters, the new water elevation all over the canal (after stabilization) is 7.04 m, corresponding to an error of 0.57 % in terms of water elevation or 0.91 % in terms of volume. If the results are given in millimeters, the new water elevation all over the canal (after stabilization) is 7.043 m, corresponding to an error of 0.61 % in terms of water elevation or 0.97 % in terms of volume.

Test With Ramp Discharge as Inflow

For a time step of 10 minutes, some deviations can be seen, compared to the "USM solution", but not really oscillations. For smaller time steps (2 and 1 minutes), the accuracy seems to be very good. Comparison of model outputs for the different time steps are presented in Figure 1. Numerical results (for a time step of 1 minute) are given in Annex 2 for comparison with other models.
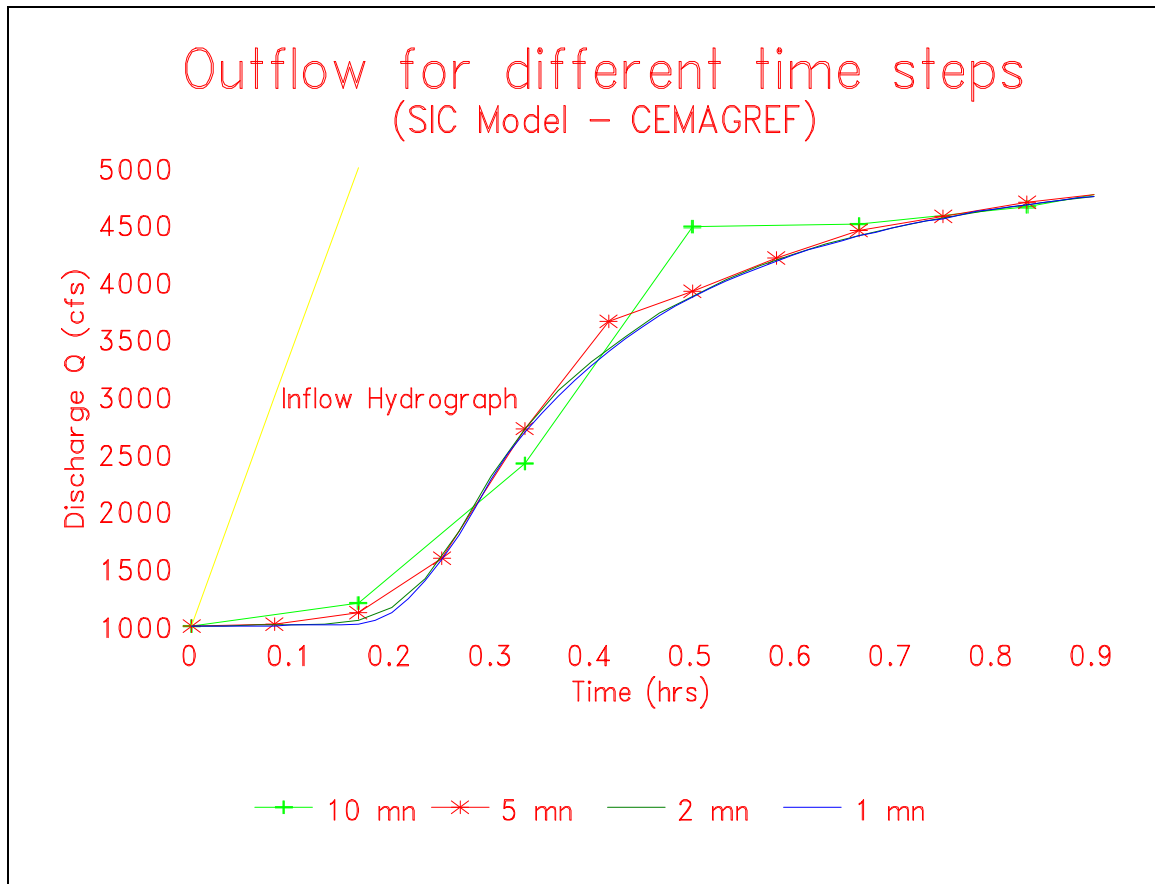

Figure 1 - Test with ramp discharge

Robustness

When an error is detected during the computation (either in steady or unsteady flow) a message is displayed in a window, indicating the type of error and the location when illicit flow conditions are detected (e.g. dry bed). In some cases, when it is possible, the computation keeps on going. In other cases it stops after displaying the error message.

Initial conditions

The SIC model is divided into three units. Unit 1 is the topographical unit used to enter topological and geometrical data of the system. Then, Unit 2 is used to make steady flow computations on this system, given the boundary conditions (discharges, gate openings, etc.). Then from one of theses steady states, or from a previous unsteady flow state, Unit 3 can perform unsteady flow computations, given the evolution of the boundary conditions in function of time.

In order to easily establish a desired initial steady state (common situation for irrigation canal management purposes), some features have been implemented in Unit 2. For example, if a targeted water elevation is given upstream of a gated cross structure, then the model can automatically compute the required gate opening in order to reach this water elevation. Unit 2 also computes the gate opening at a gated offtake, the crest width or elevation at a weir offtake, in order to match a given targeted offtake discharge, or the real supplied discharge given the offtake dimension and setting.

Internal and external boundary conditions analysis

When describing the system topology, the user has to indicate the locations (called nodes), where an inflow (e.g. headworks) or outflow (e.g. turnouts) will occur. The canal portion between two nodes is called a reach. In Unit 2, a Manning coefficient and a seepage value can be indicated at each data cross section. This allows to take local changes into account. The downstream boundary conditions are given in terms of rating curves. Cross structures and node devices are described in this Unit 2. They are able to simulate many hydraulic conditions. At cross structures, the different flow conditions can be simulated: free flow, submerged, piped, open flow, overtopping, and the corresponding transitions from one condition to another one. One cross structure contains up to 5 gates and up to 5 weirs, with different sizes, sill elevations, discharge coefficients, etc.

At nodes, several types of offtakes can be modeled: imposed discharge (e.g. headworks or pumps), gated offtake, weir or pipe with downstream condition (constant elevation, weir, user's defined rating curve), rating curves (turnout discharge function of water level in the main canal, e.g.: weirs). In the case of a gated offtake, weir or pipe the program can also handle the different hydraulic conditions (free flow, submerged, piped and open flow).

Special Hydraulic conditions

The SIC model does not handle advance on a dry bed, nor channel dewatering, nor hydraulic jumps. If this occurs, an error window is displayed and the program stops. Supercritical flow is ignored in steady flow computations, by taking the critical depth at the corresponding locations. This solution allows to continue the computation where it is possible. A warning is given to the user. Supercritical flow can be allowed in unsteady flow computations, through a simplified modelization, if the corresponding option has been selected.

MODELING CAPABILITIES

System configuration

Branching and looping systems can be handled in steady and unsteady flow computation.

Frictional resistance

The channel friction is represented using the Manning (or Strickler) equation. The Manning coefficient can vary from one data cross section to another.

Boundary condition types

Lots of boundary conditions can be taken into account:

- check gates (up to 5) and weirs (up to 5) in the same cross structure,

- inverted siphons, pumps, drop structures,

- reservoirs in series,

- siphon with gated inlet, etc.

Rating curves can be defined at the downstream boundary conditions and at the offtakes. Discharge hydrographs can be defined at nodes (headworks and offtakes). Stage hydrographs can be defined at the downstream boundary condition.

Turnouts

Through the user-friendly interface, three types of turnouts can be described:

a) Pumps, also called Imposed Discharge. Discharge can be positive (headworks) or negative (turnouts). In steady flow computation the targeted discharge has to be given. In unsteady flow computation a discharge hydrograph can be given.

b) Gates, weirs or pipes with downstream condition (constant elevation, weir, user's defined rating curve). In steady flow computation two main options are available. If the targeted discharge is given, the model computes the gate opening required to satisfy this targeted discharge. If the gate opening is given, the model computes the supplied discharge. In case of a weir the same options are available using the crest width or elevation instead of the gate opening. If a problem occurs at an offtake, a message indicates the type and reason of the problem.

In unsteady flow computation, two options are also available. In discharge computation mode, the model computes the real supplied discharge knowing the gate opening operations. In opening computation mode, the model computes the required gate opening operations (or crest width or elevation for a weir) to satisfy a demanded discharge hydrograph.

c) Rating curves. The model computes the real supplied discharge, depending on the water elevation in the main canal.

One turnout can be described at each "node" defined in the network topology.

Three types of discharges or volumes are computed at turnouts during unsteady flow computations: demanded, supplied and efficient. The efficient discharge is computed using a minimum and a maximum percentage bellow or above which (with reference to the demanded discharge) the supplied discharge is not efficient and therefore considered as wasted. Then, indicators are calculated as different ratios of these discharge or volume values. Time lags are also computed between demanded and supplied discharges.

Operations duplication

The gate opening operations can be described at each cross structure and turnout. This can be done through the user-friendly interface or through a regulation module (Cf. next section).

Automatic Control

Automatic control of any structure (cross structure, offtakes, boundary conditions) is possible inside SIC. First, the measured, controlled and control action variables have to be specified. Some parameters can be specified concerning these variables (e.g. minimum gate movement, minimum and maximum values, measure and control time step, etc.). Second, the design technique has to be specified. The most common techniques are already available (PID, BIVAL, ELFLO, interactive manual control, etc.). An open regulation module is given to the user, where any other type of control can be written in FORTRAN programming language. In addition, an interface with the

commercial package MatLab allows to write directly the regulation modules as a MatLab function, and allowing to use any MatLab function (included graphical functions).

Miscellaneous limitations

Right now the model limitations are: 20 branches (defined as linear series of reaches), 200 reaches, 1800 computation cross sections, 200 cross structures, 500 devices (in cross structures), 16 modifications in hydrograph laws, 750 time steps for unsteady flow results (the storage time step is automatically adapted knowing the computation time step and the simulation duration). A reduced version for educational purpose is available: 2 branches (defined as linear series of reaches), 10 reaches, 250 computation cross sections, 10 cross structures, 10 devices

Time step can be changed from 0.01 to 999.99 minutes (10 minutes is the default value). Distance step can be changed (default value is 200 meters). The implicit coefficient θ is set to 0.6 and cannot be changed by the user. Simulation duration is up to 99 days, but a storage time step is calculated to get a maximum of 750 stored values on the result files.

USER CONSIDERATIONS

User interface

Lots of efforts have been devoted to develop a user-friendly interface for the SIC model. It is menu driven and has lots of graphical possibilities (editor and display). The locations where data have to be entered (or results to be visualized) are identified through direct reference to the topological sketch.

Topographical unit:

The network topology is created or modified through a graphical editor (Figure 2), mouse driven (if any, or keyboard if no mouse available). This editor is interactive and checks for errors. Reach geometry is entered using user-friendly interface.

Different types of cross sections are proposed through the SIC user-friendly interface: offset / elevation, width / elevation, rectangular, trapezium, triangular, culvert, power relationship, circle.

When describing the system geometry, the user has to indicate all the data cross sections. This data can come from a topographical survey or some design documentation. Each cross section can be of a different type. If one of these sections contains a cross structure, it has to be indicated at this stage. The cross devices will be described in Unit 2 with all the hydraulic parameters.

The shape of the sections can be visualized in a graphical window. Errors are checked. Sections can be duplicated, inserted, deleted.

Additional computation cross sections are automatically interpolated in order to fit into the given distance step (default value = 200 m).
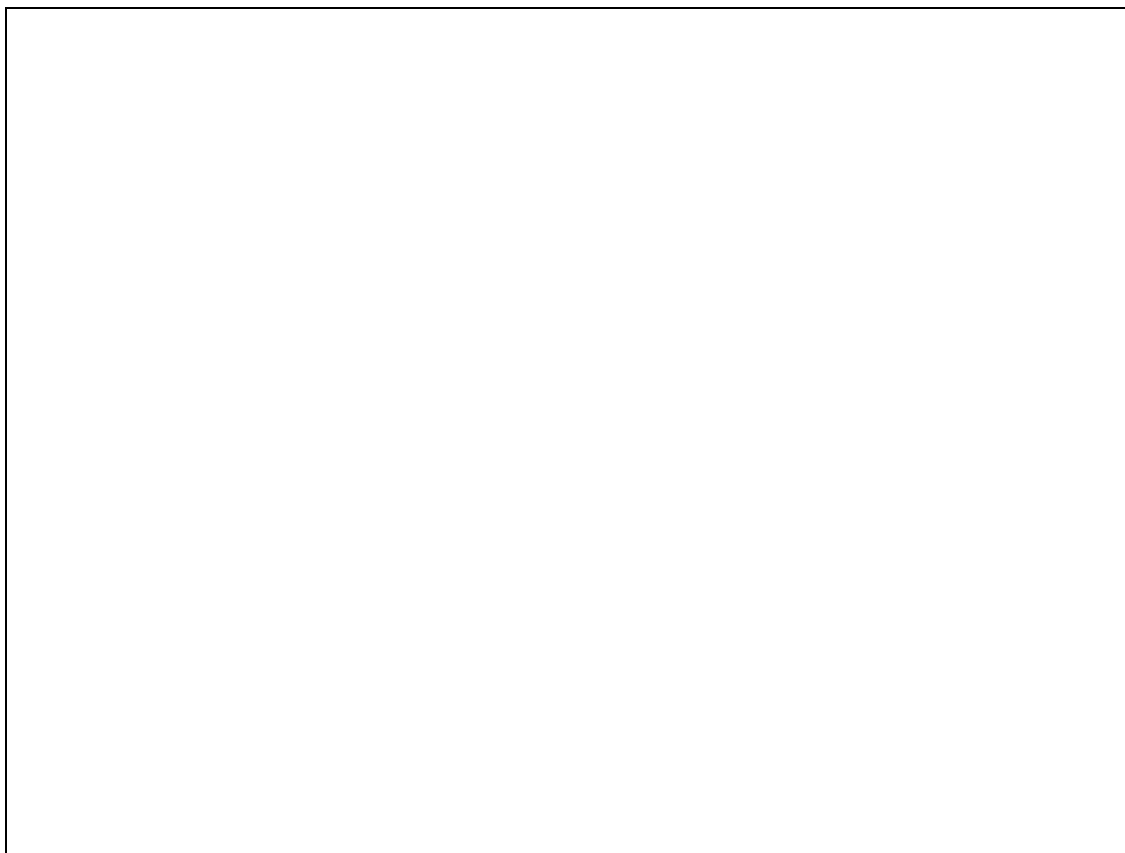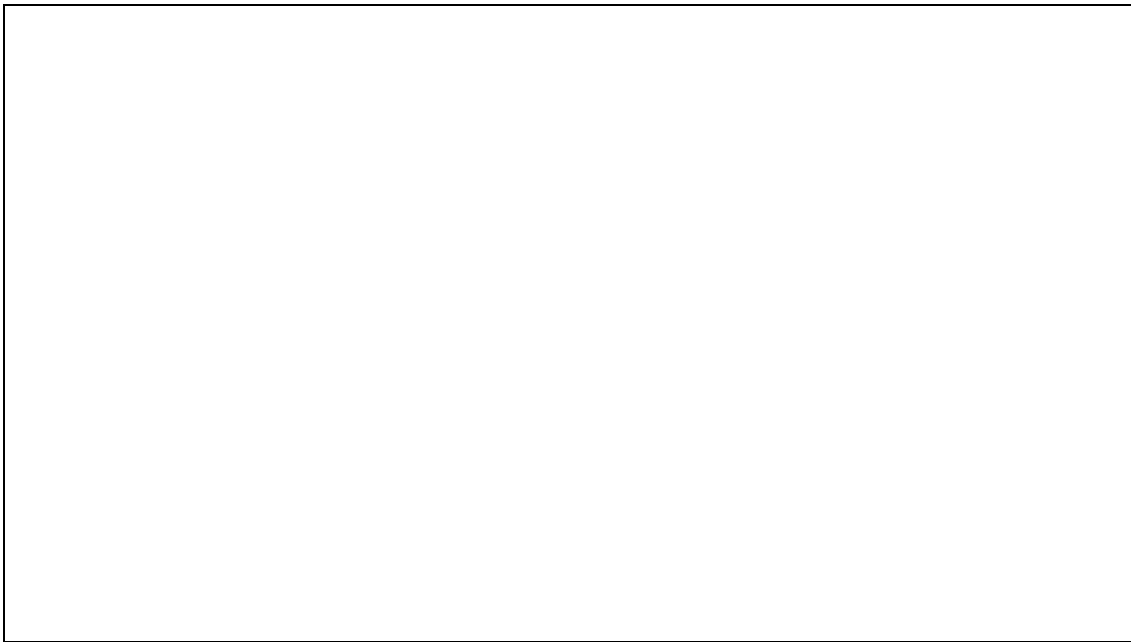
Figure 2 - Graphical editor

Figure 3 - Describing an offtake

Steady flow unit:

Data is entered using a user-friendly interface (drawings of turnouts (Figure 3) or cross devices, easy selections for Manning coefficients or seepage values, etc.). The friction coefficients (and also the discharge coefficients for gates and weirs) can be automatically calibrated by the SIC model. This calibration is made using water elevations measured along the canal. Even though calculated coefficients have to be checked and analyzed, this tool can be very useful for the model users since calibration is usually a long and laborious task. The canal sketch is displayed during the steady flow computation allowing to follow the calculation, and get warnings or errors, if any. A summary for warnings or errors is given at the end of the computation.

Then, all the results can be visualized through numerical or graphical outputs (Figure 4). Also ASCII files can be created for further use through a spreadsheet software. AutoCad DXF files can also be created for further use in the AutoCad commercial package. Graphics can be sent to a plotter or printer (in HPGL format). Automatic maximum scales are calculated; user's scale is also available.
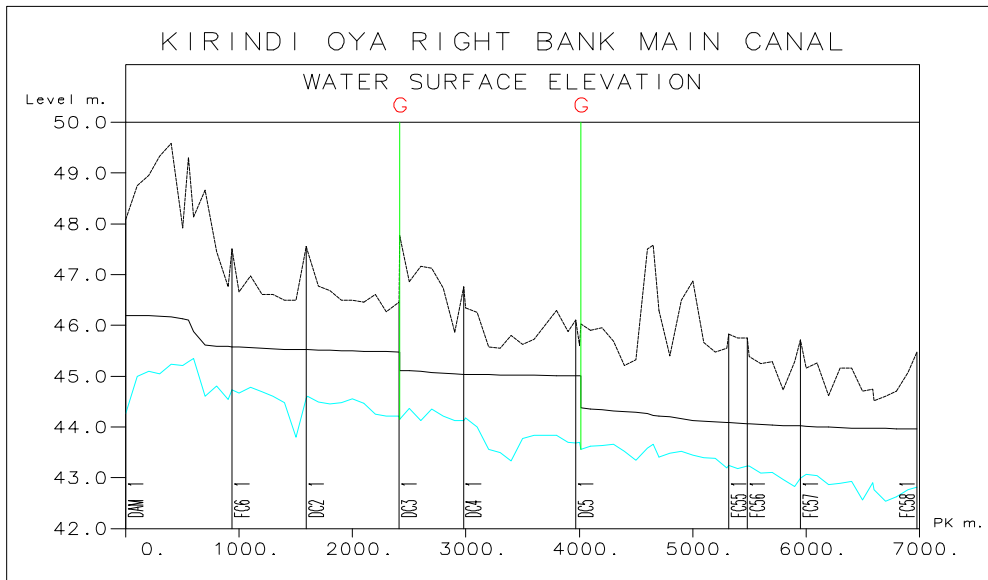
Figure 4 - Graphical output

Unsteady flow unit:

All hydrographs are entered using a user-friendly interface. Discharges and volumes (at headworks, turnouts and tail ends) are displayed during the unsteady flow computation allowing to follow the calculation. Efficiency indicators are also displayed. Then, all the results can be visualized through numerical or graphical outputs (Figure 5): water levels over time or location, flow rates, gate openings or efficiency indicators over time.

Also ASCII files can be created for further use through a spreadsheet software. Graphics can be sent to a plotter or printer (in HPGL format). A dynamic visualization can be run, displaying the backwater curve and its movement in function of time.
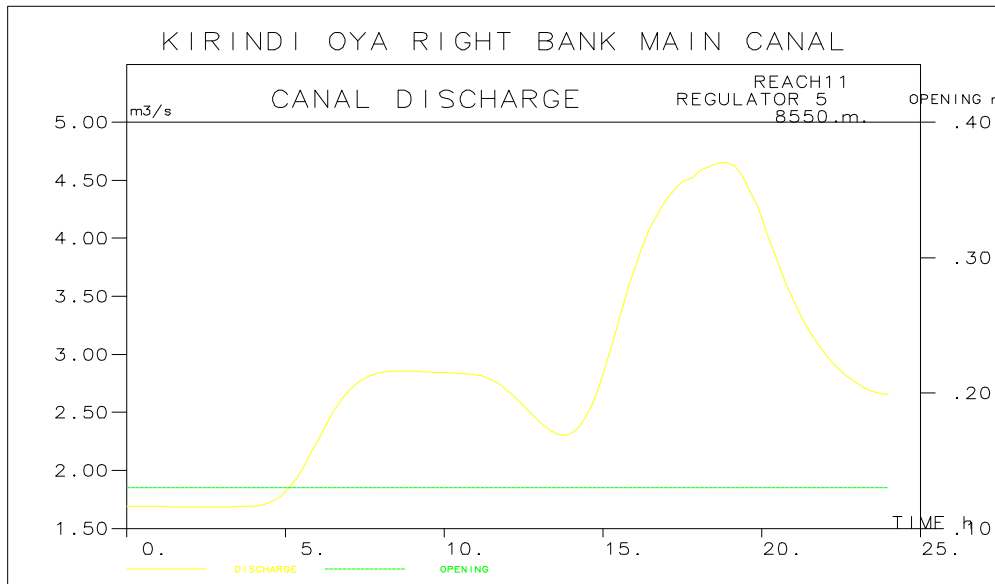

Figure 5 - Graphical output

Documentation and support

An on-line help is available. When pressing F1 key, a window is opened giving information on the current task. An interfaced installation tool is provided with the SIC model on the installation diskettes. The model interfaces, on-line help and documentation exist in French and English (soon in Spanish). A User's Guide and a Theoretical Concepts Guide are available. The User's Guide contains a complete description of the model, a chapter on how to write a regulation module, another one on how to solve problems, etc.. The Theoretical Concepts Guide contains all the details about the modelisation used (equations, numerical scheme, algorithms, devices modelisation, etc.).

Direct costs

The purchase price of the SIC hydraulic model is 80 000 FF. ($\approx$ 16 000 US dollars) for the professional version and 5 000 FF. ($\approx$ 1 000 US dollars) for the reduced educational version.

The hardware requirements are: IBM PC or compatible, Windows 3.1, 3.11 or 95, Math coprocessor, EGA or VGA graphic monitor, 3.5" disk drive 1.4 MB, Hard disk (10 MB required). Possible options are: Plotter or HPGL compatible printer. No additional software is required, except FORTRAN Compiler Microsoft®, if a new regulation module is to be designed. Interfaces to MatLab and AutoCad are proposed.

Steady flow and unsteady flow units can be freely distributed to final users (e.g. canal managers) on their specific canal network. The topographical unit of the model is protected with a dungle. Therefore, this unit cannot be duplicated and cannot be run on more than one computer at the same time.

Indirect costs

Two days training are included in the purchase price of the professional version (in Montpellier - France).

CONCLUSION

The SIC hydraulic model combines efficient numerical algorithms and up-to-date user-friendly interfaces. Developed in close collaboration with the engineers and managers partners of the SIC User's Club, it fulfills most of the user's needs, as far as irrigation canals are concerned. It has been already used in many different countries: France, Sri Lanka, Pakistan, Burkina Faso, Mexico, Jordan, Senegal, etc.. New technical features and new interfaces should be introduced in the next updated versions.

REFERENCE

[1] Dinshaw N. Contractor and Wytze Schuurmans, "Informed Use and Potential Pitfalls of Canal Models", Journal of Irrigation and Drainage Engineering, Vol 119, n° 4, July/August 1993.

ANNEX 1: ACRONYMS AND ABBREVIATIONS

ASCE: American Society of Civil Engineers

BCEOM: Société Française d'Ingénierie

CACG: Compagnie d'Aménagement des Coteaux de Gascogne

Cemagref: Centre National du Machinisme Agricole, du Génie Rural, des Eaux et des Forêts

CNABRL: Compagnie Nationale d'Aménagement du Bas-Rhône Languedoc

ENGREF: Ecole Nationale du Génie Rural, des Eaux et des Forêts

IBM PC: International Business Machine™ Personal Computer

IIMI: International Irrigation Management Institute

LAAS: Laboratoire d'Automatique et l'Analyse des Systèmes

LHF: Laboratoire Hydraulique de France

MAE: Ministère des Affaires Etrangères

MCoop.: Ministère de la Coopération

MRE: Ministère de la Recherche et de l'Espace

OIE: Office International de l'Eau (ex CEFIGRE)

SCP: Société du Canal de Provence

SIC: Simulation of Irrigation Canals

SOGREAH: Société Grenobloise d'Etudes et d'Applications Hydrauliques

ANNEX 2: TEST WITH RAMP DISCHARGE AS INFLOW

Numerical results for a time step of 1 minute

Time (hrs)	Inflow (cfs)	Outflow (cfs)	USM values (approximate)
0	1000	1000	1000
0.017	1400.007	1000	
0.033	1800.014	1000	
0.05	2199.633	1000	
0.067	2599.993	1000	
0.083	3000	1000	
0.1	3400.007	1000.071	1000
0.117	3800.014	1000.353	
0.133	4199.986	1001.589	
0.15	4599.993	1005.968	
0.167	5000	1018.681	
0.183	5000	1049.829	
0.2	5000	1118.974	1155.2
0.217	5000	1235.194	
0.233	5000	1391.955	
0.25	5000	1580.393	
0.267	5000	1791.821	
0.283	5000	2034.361	
0.3	5000	2275.1	2482.8
0.317	5000	2491.436	
0.333	5000	2684.077	
0.35	5000	2849.278	
0.367	5000	3001.448	
0.383	5000	3142.282	
0.4	5000	3275.735	3448.3
0.417	5000	3397.606	
0.433	5000	3508.14	
0.45	5000	3609.316	
0.467	5000	3701.593	
0.483	5000	3786.03	
0.5	5000	3863.651	3982.8

0.517	5000	3936.646	
0.533	5000	4004.45	
0.55	5000	4066.992	
0.567	5000	4124.801	
0.583	5000	4178.303	
0.6	5000	4227.92	4293.1
0.617	5000	4275.17	
0.633	5000	4319.349	
0.65	5000	4360.42	
0.667	5000	4398.665	
0.683	5000	4434.333	
0.7	5000	4467.705	4465.5
0.717	5000	4499.029	
0.733	5000	4528.516	
0.75	5000	4556.309	
0.767	5000	4582.512	
0.783	5000	4607.409	
0.8	5000	4630.928	4603.4
0.817	5000	4653	
0.833	5000	4673.73	
0.85	5000	4693.188	
0.867	5000	4711.481	
0.883	5000	4728.644	
0.9	5000	4744.782	4706.9
0.917	5000	4759.932	
0.933	5000	4774.199	
0.95	5000	4787.583	
0.967	5000	4800.155	
0.983	5000	4811.986	
1	5000	4823.11	
1.017	5000	4833.563	
1.033	5000	4843.38	
1.05	5000	4852.597	
1.067	5000	4861.285	
1.083	5000	4869.442	
1.1	5000	4877.106	
1.117	5000	4884.31	
1.133	5000	4891.125	
1.15	5000	4897.517	
1.167	5000	4903.521	
1.183	5000	4909.171	
1.2	5000	4914.504	
1.217	5000	4919.483	
1.233	5000	4924.215	
1.25	5000	4928.629	
1.267	5000	4932.832	

1.283	5000	4936.752	
1.3	5000	4940.424	
1.317	5000	4943.921	
1.333	5000	4947.205	
1.35	5000	4950.277	
1.367	5000	4953.173	
1.383	5000	4955.928	
1.4	5000	4958.505	
1.417	5000	4960.907	
1.433	5000	4963.202	
1.45	5000	4965.356	
1.467	5000	4967.369	
1.483	5000	4969.276	
1.5	5000	4971.042	
1.517	5000	4972.737	
1.533	5000	4974.326	
1.55	5000	4975.81	
1.567	5000	4977.222	
1.583	5000	4978.564	
1.6	5000	4979.8	
1.617	5000	4981.001	
1.633	5000	4982.096	
1.65	5000	4983.155	
1.667	5000	4984.108	
1.683	5000	4985.062	
1.7	5000	4985.91	
1.717	5000	4986.722	
1.733	5000	4987.499	
1.75	5000	4988.24	
1.767	5000	4988.911	
1.783	5000	4989.547	
1.8	5000	4990.183	
1.817	5000	4990.748	
1.833	5000	4991.277	
1.85	5000	4991.807	
1.867	5000	4992.266	
1.883	5000	4992.725	
1.9	5000	4993.149	
1.917	5000	4993.537	
1.933	5000	4993.926	
1.95	5000	4994.279	
1.967	5000	4994.597	
1.983	5000	4994.915	
2	5000	4995.197	