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Design of a Decision Support Tool to Improve Manual Operation Procedures of an Irrigation Canal

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Abstract:
Engineers have been using mathematical models for more than 20 years to design, improve and study irrigation canals. More recently these models have also been used to develop and test regulation algorithms (including complex automatic control algorithms), prior to field implementation, for the automation of the control structures located along the canals.

Unfortunately, only advanced users were able to run these mathematical models since no particular effort had been devoted for their input and output interfaces.

In 1987 a collaboration was initiated between IIMI and CEMAGREF, prospecting the possibility to give irrigation canal managers a decision support tool that could help them in their daily operational procedures. The selected site for the field applications, in close collaboration with the local Irrigation Department (ID), was the Kirindi Oya right bank main canal in Sri Lanka.

The paper focuses on:

- The context of the study,
- The terms of references,
- The required type of mathematical model,
- The development of the mathematical model (called RBMC),
- The first uses,
- The improvements and perspectives.

The field applications of this model and the achieved results are not discussed in this paper. Another paper presented by IIMI and the ID focuses on this aspect.

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1 Introduction

More than 280 million hectares of land are irrigated all over the world. During the last three decades, the development of irrigated surfaces has been continuous, with an annual increase of about 4 million hectares.

Most of these irrigated schemes have a poor hydraulic efficiency (30 % to 50 %) and therefore cannot reach the initial targets (one main objective of irrigation is to increase and to secure food production with its positive social and economic consequences).

Efforts have been devoted to improve the functioning of such schemes, at different levels:

- institutional and social: laws, rights, organisation, participation, training, etc.,
- structural: by upgrading physical structures and infrastructures (main and secondary canals, check devices, turnouts, etc.),
- operational: by improving operational practices on the regulation and distribution structures.

In fact very few efforts have been devoted to the improvement of this latest component. We will focus, in this paper, on the operational practices concerning main canals, which are a key component of most irrigated schemes. It is now admitted that problems at the farm level are often due to problems at the main canal level. Nevertheless, we will keep in mind that the success of any project will depend on the interrelated success of all its different social and technical aspects.

2 Operating an irrigation canal

An irrigation canal is mainly a conveyance system allowing to transport water from a collecting structure (usually a dam) down to users (cultivated farms, other storage ponds, etc.). This must be done with some constraints or operational targets: to deliver water at a given location, flow rate/volume, and time/duration to fulfil user's requirements mainly linked to crop requirements.

In order to manage such a system, and operate it properly so as to reach projected operational targets, lots of different devices (headworks, cross structures, delivery devices, spillways, etc.) have been designed and installed on irrigation canals. Staff from ID is responsible, among other tasks, to the management of these devices.

Depending on the location (continent, country), on the age of the system, and on the financial possibilities, etc. different type of devices, different logic of control can be found world-wide.

Some of these devices are fixed (weirs, spillways, etc.). The design phase is therefore important since the future operational behaviour will entirely depend on this phase. Future O&M[3] activities will only focus on Maintenance aspects.

Some other devices are moveable (gates at cross structures or offtakes, main sluice gates, etc.). Design phase is still important since errors during this phase could result in future operational problems. Maintenance will also be an important issue. In this case an additional operational activity will appear. It will consist in operating these devices at a certain location and time in order to reach (or at least try to reach) water distribution targets.

[3] Operation and Maintenance

This issue is important because the operation of these moveable devices is complex. Moreover, the canal behaviour and the distribution efficiency are directly linked to these operations. It is complex for different reasons (examples are given for the Kirindi Oya right bank main canal):

- size of the system (several tens or hundreds of kilometres long - e.g. 25 km), resulting in:

  * long time lags for the transport of water (several hours or days - e.g. around 15 hours from the dam to the tail end),
  * increased time required for the canal managers to operate at different locations,
  * coordination lacks between the different operators,
  * difficulties to get real time feed back on the canal state, etc.,

- number of devices (e.g. 2 main sluices, 36 offtake gates, 14 cross regulators with a total of 66 gates),

- complex hydraulic phenomenon:

  * varying time lags due to the non-linearity of the governing Saint-Venant equations and to settings or operations at cross structures,
  * diffusion phenomenon,
  * relation between delivered discharges and water levels at offtakes,
  * different behaviours linked to submerged / free-flow conditions, open-flow / pipe conditions, subcritical / supercritical conditions, and the corresponding transitions between these different flow conditions, etc.,

- unknown perturbations occurring on the system (illegal water withdrawal, rains, blocking of a gate with floating elements, etc.).

These difficulties are one of the main reasons explaining the poor control over the main canal. This results in a mediocre control over the on-farm water distribution, explaining a low water efficiency and equity on the district.

Some solutions have been considered in order to face these difficulties.

3 Possible improvements

In order to facilitate or improve the operation of irrigation canals, different solutions are possible.

a) Using local automatic devices (duck bill weir, calibrated distributor, Amil gate, etc.). This solution facilitates the operation of the system, by reducing the number of devices to be operated. Some other moveable devices have still to be operated. Therefore the way the system is operated and the organisation of the ID is not greatly changed. This solution increases the investment and maintenance costs.

b) Operating devices through a remote control system, or through automatic regulations (either local or centralised). This solution induces important changes on the organisation of the ID, since all the operations will be decided and run from a remote control office. Investment and maintenance costs will be highly increased. This cost will be compensated by staff reduction and improved control over the system, both in routine and emergency operations. This results in higher water efficiency in the district.

Unfortunately, this solution cannot be selected, right now, for irrigation canals in developing countries. The main reasons are economical and sociological: expensive investments particularly compared to labour costs, high technical skills required for operation and maintenance, etc.

c) Giving to the canal managers a decision support tool that could help him in his Operation and Maintenance activities. This approach became possible, with the recent development of interfaced softwares running on micro-computers. It can be selected for irrigation canals in developing countries since it requires minimum financial and technical inputs. The general idea, further developed in the next sections, is to give to the canal managers a decision support tool, based on a mathematical model representing his irrigation canal. This model will be interfaced to be easily and directly used by the canal manager. With this solution, the canal operations are still manual but improvements are prospected through this tool. The use of the model will be detailed in the following sections.

This latest solution has been tested through a collaboration between IIMI and CEMAGREF. The project started late 1986 with the selection of the irrigation canal to be modelled (Pochat R., Berthery D., Rao P.S.). The criteria for the site selection were:

- water delivery problems faced on the district, type of existing management rules,
- structural characteristics of the site (devices, turnouts, reservoirs, canals, etc.),
- available data (hydrology, hydraulic, topography, operations, etc.),
- participation of the local managers in the experience (development of the model, data acquisition, future use),
- characteristic of the site for future dissemination.

The Kirindi Oya right bank main canal was finally selected since it was fulfilling the above criteria and in particular:

- structure was in good conditions, therefore operational improvement was possible without structural rehabilitation,
- canal was simple to be modelled: trapezium cross sections, double bank canal, simple cross devices and turnouts (gates and weirs),
- project for crop diversification, justifying prospects to improve control over water distribution,
- available data, or easy to be collected (recent canal),
- characteristic of irrigation canals.

The project started with the idea to disseminate the methodology to other sites as soon as possible, once the test proved to be successful in Kirindi Oya.

4 Terms of references

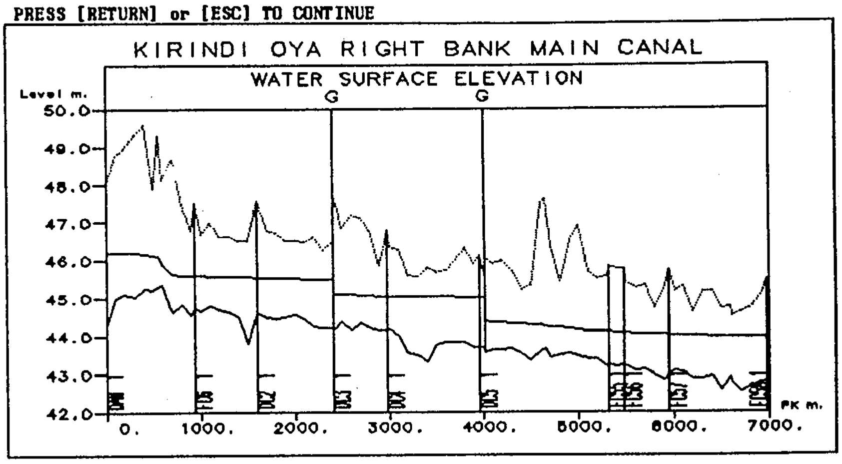
The primary objective of the project was to provide a research and training tool in the form of a mathematical flow simulation model of the Kirindi Oya right bank main canal. This tool should enable IIMI and the ID to gain in-depth knowledge of the hydraulic behaviour of the main canal. With this tool it would be possible to evaluate the impact of different canal operational practices on the performance of the system (e.g. due to changes in irrigation water demand).

The model should accurately simulate the behaviour of the Kirindi Oya right bank main canal so that canal managers could recognise "their" canal. The RBMC simulation model was designed to run on a microcomputer (IBM PC or compatible) used by the ID, with special care to get high performances in terms of computation speed and memory capacity.

Three CEMAGREF programs available on mainframe computers (TALWEG, FLUVIA and SIRENE) were used to design the model. The model is therefore divided into three units:

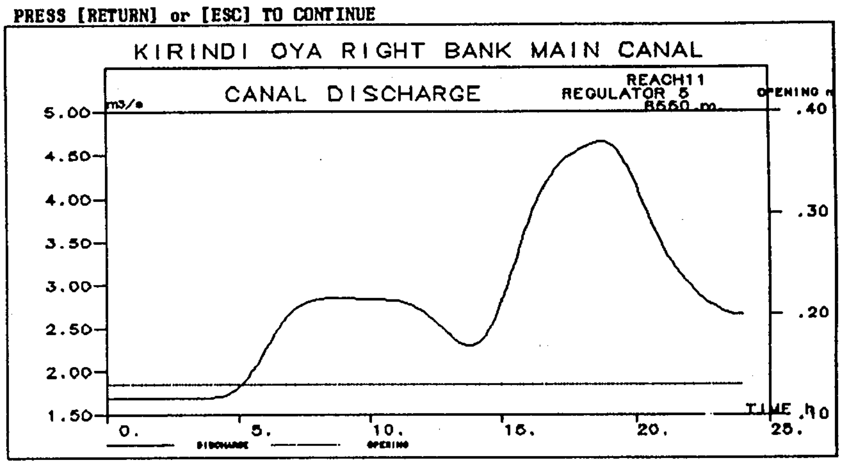
The first unit (Topography) allows to input and check the topography data of the canal and generates the data files used by the other two units of the simulation model. The use of this unit is restricted to specialists.

The second unit (Steady flow) calculates the water surface profile as well as the offtake and regulator gate openings for any set of water demand.



Example of steady flow output

The third unit (Unsteady flow) simulates the flow conditions in the canal after modifications of internal and external boundary conditions: gate settings and changes in water inflows and outflows. The user is thus able to evaluate the consequences of any given operation before actual field implementation.



Example of unsteady flow output

A major component of the project was the development of a user friendly interface allowing non-specialised people from IIMI and ID to use the simulation model. The data input is fully interactive. Through data editors, users give all the required information for the hydraulic computation. Moreover, the data editors give advanced users access to specific data. The model can be used easily and outputs are designed to provide operational assistance to the canal managers. Displays of simulation results include graphics and tabulated outputs. Model features and outputs meet the needs of different types of users with various interests in using the model and different levels of practical and theoretical experience in hydraulics. The user interface allows to handle all the features of the simulation model, managing spatial and temporal information.

The RBMC model has a modular structure allowing partial modifications, additions and substitutions of modules. Programs corresponding to the hydraulic algorithms included in the model, in particular FLUVIA and SIRENE, could be changed by upgraded versions that

CEMAGREF will develop in the future. The general layout of the model includes the possibility to add regulation modules allowing the simulation of gate operations through various management rules or control algorithms.

5 The required type of mathematical model

The model is designed to accurately simulate the hydraulic behaviour of the Kirindi Oya right bank main canal. It means the model should be able to correctly represent the singularities influencing the hydraulic behaviour of the canal. The model is limited to the main canal and its various structures. It takes into account the real geometry of the canal, gated cross regulators, offtakes of various types with special efforts to the modelisation of their downstream conditions. The program contains procedures to prevent errors during the hydraulic simulations, as well as facilities to generate initial hydraulic conditions.

The full Saint Venant equations for unsteady flows are solved through the implicit Preissmann scheme. The initial steady flow condition is computed by the standard step method. The steady flow unit computes the water surface in the various reaches of the canal for any given set of inflows, cross-regulator positions and offtake gate openings. The user can also determine regulator gate settings to achieve a given water distribution plan at Full Supply Depth (FSD). The unsteady flow unit computes the hydraulic conditions that occur when the control structures and offtakes are operated. This unit allows the user to test various scenarios of water demand and scheduled operations at the headworks and control structures. For example, different operational practices can be tested to achieve a transition from one initial steady flow regime to another one, corresponding to a change in the water distribution. The user can compare the results of different operational plans with respect to the water efficiency and labour cost through indicators and synthetic reports (number of operations at structures, indicators at offtakes).

6 Development of the model

A study advisory committee (SAC) composed of several international experts in mathematical modelling and a representative of the French Ministry of Foreign Affairs sponsoring the project was set up to define and follow the project, provide technical advises and control the model development.

The project was implemented in three phases corresponding to the three units of the model. The major part of the project consisted in designing user friendly interfaces. However, it is difficult to specify all details and functions of the user interface. Such details were better identified in collaboration with model users. Therefore at each step of the project, CEMAGREF provided a draft interface that helped IIMI and ID to define more precisely their needs. In each phase CEMAGREF installed the corresponding unit and collected additional information from the ID users. Then, CEMAGREF worked out on the final version, according to the guidance of the users and the advises of the experts of the SAC.

7 Calibration and first uses

The quality of the representation of the real canal through the mathematical model depends on the calibration phase. It consists in adjusting the different parameters used by the model: Manning's and discharge coefficients. Therefore this calibration phase is very important since the quality of future simulations will depend on it.

The first model calibration was made in April / May 1988 (Certain F., Durbec A.). This calibration was made on one steady state. Then, a wave propagation was studied to check the good correlation between measurements and model predictions in unsteady flow conditions.

The calibration allowed to evaluate model parameters: Manning's coefficients and discharge coefficients at gates and weirs. Field measurements also allowed to evaluate seepage values.

One first result was that the average Manning coefficient was around 0.045 instead of 0.025 as assumed at the design stage. This means the canal roughness is higher than predicted, and implies a reduction in the maximum conveyance capacity of the canal.

The calibration proved to be difficult due to problems in the accuracy of the topographical survey. One outcome is that this survey should be carried out with advises from a hydraulic engineer, able to detect important sections, on a hydraulic point of view. Since this phase is time and staff consuming, it would be useful to define a methodology for collecting data and processing calibration.

After this first calibration, IIMI and CEMAGREF started to use the model to study design and operational issues, in relation with the canal managers (Sally H. 1988-89, Malaterre P.O. 1989, Rey J. 1990):

- maximum capacity,
- overtopping locations,
- influence of water fluctuations in the main canal on water deliveries,
- simulation of the present operational practices and prospects of improvements on some operational scenarios,
- etc.

After these first experiences, four different applications were foreseen for the simulation model:

- To study the hydraulics and the design of the canal. It allows for example to perform some simulations on siltation, design modifications, overtopping risks, maximum discharges, etc.
- As a training tool, to test some operational practices and see their effects on the canal state. In this case the model is not used to give specific targets to the operators but rather to define some general operational rules.
- To provide real time information for manual operations. In this case communication along the canal between the ID and the operators has to be improved.
- To study a real time regulation. But in this case the manual operations have to be abandoned and new technologies have to be installed on the canal (sensors, communication lines, automatic gates, etc.).

According to the improvements the ID is ready and able to perform, one of these different applications will be chosen. Levels 1 and 2 can be achieved with no further change. For level 3 the organisation and communication among the operators have to be improved. At this level the operators have to be able to perform a computed operation at a computed time with a good precision. For level 4 the changes are more significant. This level is not advisable, right now, for small irrigation canals in developing countries (Cf. Chap. 3.b).

The model has been intensively used by IIMI and ID in 1991/1992. The article presented by Wijesekera S. and Rey J. describes in detail this application and the corresponding outcomes.

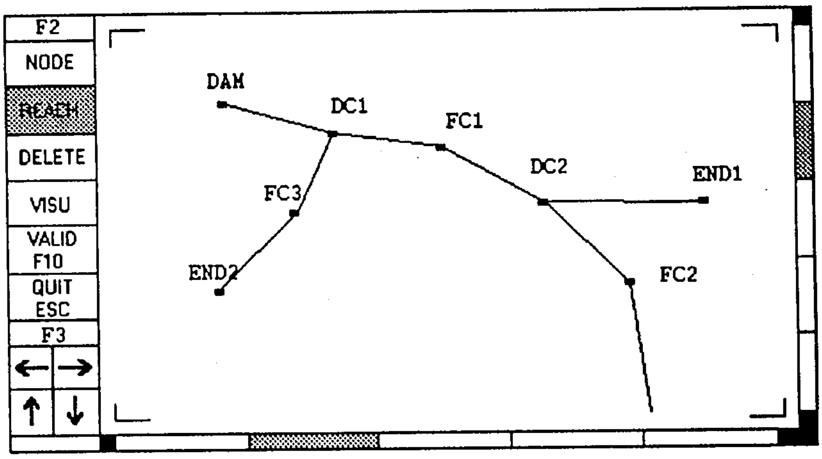
8 Improvements and Perspectives

After 4 years of use of the simulation model by IIMI, CEMAGREF and the canal managers of the ID, several lessons appeared. The RBMC model proved to be a good simulation model, giving a pleasant and accurate representation of the Kirindi Oya canal. It helped the canal managers to have new information on their canal.

The model was also used as a simulation module in a broader "decision support tool" allowing to improve the operational practices on the canal (main sluices, cross structures and offtakes). But also (and maybe more than other outcomes) it could be considered as a great catalyser allowing to foster communication and stimulate attention paid to the canal operation issue, among the different people involved (managers, institutions, engineers, etc.).

As an operational decision support tool, RBMC model proved to be insufficient. In particular interfaces of Unit 1 and 3 had to be improved. Lots of improvements already were taken into account and a new version of the software was developed by CEMAGREF, named SIC (Simulation of Irrigation Canals). In order to facilitate the calibration phase, a calibration module was added to the simulation model. It automatically computes Manning's and discharge coefficients, given a set of discharges and water level measurements along the canal.

This model is supposed to be able to simulate most of the irrigation canals world-wide, whereas the RBMC model was dedicated to the Kirindi Oya right bank main canal. In particular the topography unit (Unit 1) was interfaced.



SIC topography editor

Some other features will have to be implemented on the next versions of the model, in particular:

- looped network even in unsteady flow simulations,
- supercritical flows,
- other type of devices (cross structures and offtakes), etc.

Prospects for a new generation of irrigation software, that could be used as a decision support tool by the ID already started at CEMAGREF. This software could be based on a simple GIS (Geographical Information System), with different modules using common data through a common data base manager:

- hydrology,
- water requirements,
- hydraulic simulation of main canal (such as RBMC or SIC),
- expert system to propose operational practices, help users to input data, analyse simulation results,
- customised user friendly interfaces,
- etc.

9 Conclusion

The RBMC hydraulic model was developed on a specific irrigation canal selected as an experimental site. On this site the project evolved a lot since the first terms of references, as far as the model itself and the conditions of use are concerned. But the experience proved to be successful and produced lots of outcomes. They led to new versions of the software and information on the required features for the new irrigation decision support tools. The Kirindi Oya project also helped to design a complete methodology of use for such simulation models (Cf. paper presented by Wijesekera S. and Rey J.).

One objective of the workshop is to compare these different experiences and prospect if a common type of simulation model and methodology could be defined.

In any case, this type of project can be successful only with a strong participation of the canal managers. The active participation of ID helped a lot in the success of the Kirindi Oya right bank main canal simulation project.

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