CEMAGREF - IIMI International Workshop on
The Application of Mathematical Modelling for the Improvement of Irrigation Canal Operation
October 26 - 30 1992, Montpellier, FRANCE

Development and Application of the Irrigation Conveyance System Simulation Model

David H. Manz [1] *and Mike Schaalje*[2]

Abstract

The apparent simplicity of using open channel irrigation conveyance systems belies the actual complexity of the technology, the significant costs incurred to construct and operate such systems and the poor performance frequently experienced by irrigation projects dependent on this type of water delivery system. There is an urgent need to ensure irrigation project sustainability and optimal land, water and capital resource use. It is probable that these objectives can be achieved with the rapid development and introduction of appropriate planning, engineering and management methods. Computer models, such as the Irrigation Conveyance Systems Simulation (ICSS) Model, developed at the University of Calgary which simulate the hydraulics and operation of irrigation canals and networks of canals hold considerable promise in fulfilling most of these needs.

The ICSS Model successfully simulates the hydraulics, hydrology and operation of open channel irrigation conveyance systems as required by irrigation engineers, managers, planners and operators. Single canals or networks of canals may be simulated. The hydraulics and operations of all known types and variations of canal and hydraulic control structure may be modelled using verified theory and numerical techniques. Seepage and other distributed lateral inflow or outflow maybe considered. Model-user interfaces are tailored to the needs, experience and resources of the user. The ICSS Model has been used successfully in several projects. The acceptance of the dynamic modelling approach can be attributed to the use of verifiable theory, the ability to match model attributes to user requirements and the ability to accurately predict modelling costs and time to development.

Introduction

Background to Model Development

Open channel conveyance systems are the technology of choice for water distribution in the vast majority of irrigation projects worldwide. The technology is very common and appears to have developed independently in many widely separated regions. The apparent simplicity of using open channel systems to transport water for irrigation belies the actual complexity of the technology, the significant costs incurred to construct and operate such systems and the poor performance frequently experienced by irrigation projects dependent on this type of water delivery system.

---

[1] Associate Professor, Department of Civil Engineering, University of Calgary, 2500 University Drive N.W., Calgary, Alberta, Canada T2N 1N4, (403) 220 5503 and principal of Sim-Flo Engineering Ltd., #25, 3512-27th Street N.E., Calgary, Alberta, Canada, T1Y 5E4.

[2] Principal of Sim-Flo Engineering Ltd., # 25, 3515-27th Street N.E., Calgary, Alberta, Canada, T1Y 5E4

22414

Organizations such as the World Bank, ICID and IIMI, consider the assurance of irrigation project sustainability a priority, Le Moigne et al 1988, World Bank/UNDP 1990, and Hennessy 1991. As well, it is recognized that land and water resources for irrigation projects and the resources necessary to construct and operate them are limited and must be used in an optimal fashion.

Sustainability, as well as optimal resource use, can be achieved with the development and acceptance of appropriate planning, engineering and management methods. "Old technology" needs to be rethought and modified and "new technology" must be developed. All innovative technology, if it is "new" relative to past practice, must be assimilated into the "local irrigation engineering/management culture" whatever that may be. Without this acceptance promising technology may be difficult or impossible to introduce.

The caution is understandable if it is recognized that existing and perhaps inferior technology is still "acceptable" by virtue of being considered "standard practice". Failure of technology considered standard practice is perceived as defendable while failure of innovative technology is usually not. Unfortunately, millennia, centuries or even decades are not available for new technology, necessary for the achievement of sustainability, to be embraced into the folds of standard practice. The achievement of sustainability requires the rapid development, evaluation and introduction of appropriate technology.

It is generally desirable that maximum utility be made of existing conveyance system infrastructure. Replacement or extensive rehabilitation is frequently unaffordable and unnecessary particularly if the conveyance system is physically sound and the required performance improvements may be achieved by modifying existing management and operational practices. However, even if performance improvement is urgently required, the usual "trial and error" procedures are normally not acceptable for evaluating alternatives.

Implementation of suitable technology, which is locally or regionally new, may be seriously impeded by the complexity of the required training and other technology transfer processes. Learning through field experimentation may be the ideal approach, particularly where operations and management are concerned, but is almost never practical. If the technology has been introduced and is functioning properly, field training is the technology transfer method of choice.

In summary managers, planners, engineers and operators of irrigation projects which employ extensive open channel systems have been limited in adopting technology required to assure project sustainability. Methodologies are required with which to:

1. Evaluate the performance of existing or proposed systems;
2. Develop and introduce innovative designs and operational and management strategies;
3. Assess, develop and introduce appropriate rehabilitation and maintenance programs; and,
4. Train personnel associated with irrigation projects, particularly the conveyance system.

Computer models which simulate the hydraulics and operation of irrigation canals and networks of canals hold considerable promise in fulfilling most of these needs. It is very important to recognize that the modelling technology is not new, e.g. Preissmann 1961 and Amorocho, J. and Strelkoff 1965. The initial developments coincided with the introduction and general availability of modern computer technology. The underlying theory describing the flow of water in open channels has been known since the mid-nineteenth century and is named after its originator, Guy de St. Venant.

The solution of the equations associated with this theory was made routine with the availability of modern computers. Despite early successes and tremendous advances in modelling technology, computer simulation of the hydraulics and operation of irrigation conveyance systems has not as yet gained wide acceptance.

The following reasons are offered:

1. Successful model development requires a thorough understanding of complex theory and numerical techniques and very good computer programming skills.

2. Existing models, despite claims to the contrary, frequently do not meet the needs and expectations of their intended users. Many modellers do not understand or appreciate user needs. Many modellers oversell their product.

3. Models are expensive or are perceived as being expensive to use or implement.

4. Model verification and calibration, though important, are seriously misunderstood processes. All of the dynamic simulation computer models of open channel irrigation conveyance systems use the same fundamental equations which have been exhaustively verified; and, calibration is not very different from that traditionally used for nearly a century of steady flow analysis.

5. Computers have only recently become sufficiently capable, inexpensive and accessible to the majority of intended users.

6. Commercial software needed to support the modelling activity on smaller affordable computers has only recently been made available, (compilers, extenders etc.).

7. Until recently successful applications of computer simulation models of irrigation conveyance systems have been uncommon.

8. Demand for sophisticated operation and management technology, such as automation and expert systems, is relatively recent. Challenges suitable for the application of computer simulation technology are only now being identified.

9. Model-user interfaces do not match user needs. Intended users have frequently been reluctant to use models because they were often required to be experts in most of the technology required to develop the model. This is of course quite unrealistic. Many of the intended users of these models will have no knowledge whatsoever of model technology and will not wish to learn it. Their only interest is the application of the model as a decision aid. Many users would not use these models if they could possibly avoid it. For models to be readily accepted user needs must be carefully considered and accommodated.

10. Model users with some expertise in hydraulics do not necessarily have confidence in the technology included in the simulation models. Many models use nontraditional approaches which though correct are quite different from conventional/traditional methodology or "standard practice".

11. Model development and/or configuration costs are often not explicitly stated or known. Most applications reported are in a subsidized or research environment. Models capable of being used in a true cost recovery capacity are not common. Each modelling application cannot be considered a research endeavour or user confidence will not grow and there will be an understandable reluctance to use modelling

technology. The training and experience of the model developer(s) are major factors.

12. Time to develop and/or configure models for specific applications is usually not provided if known. Again, most applications reported are in a subsidized or research environment. For models to be included in planning and engineering activities model development and/or configuration time must be known, and defendable, in order to be properly considered in the overall project management. The training and experience of the model developer(s) are major factors.

13. Long term technical support for the model may not be assured. This may not be as important to users who wish to use the models as part of short term projects.

14. Competitiveness among model developers, though healthy, has confused potential model users regarding the factors which they must consider in model selection.

General Description of the ICSS Model

The Irrigation Conveyance System Simulation Model (ICSS) Model was developed as an aid in the performance evaluation of open channel irrigation conveyance systems, Manz 1985. The model has since undergone many changes and bears only superficial resemblance to the original versions. The intended function of the model has been expanded to incorporate real time operations assistance and training while continuing to serve as an aid to irrigation engineers, managers, planners and operators for the design, rehabilitation, management, operation and maintenance of irrigation conveyance systems. It was recognized at the outset that system performance, using criteria of choice, needed to be related to the physical, operational and hydrologic characteristics of the system and that the most effective method to determine these relationships was dynamic simulation modelling. This conclusion is supported by the International Irrigation Management Institute in their work in Sri Lanka, IIMI 1988. Dynamic simulation models of irrigation conveyance systems such as the ICSS Model promise to provide opportunities to:

1. minimize water losses from conveyance systems,
2. minimize capital and rehabilitation costs,
3. minimize management and operational costs,
4. minimize maintenance costs,
5. allow additional land to be irrigated by maximizing the use of existing infrastructure capacity,
6. improve safety of conveyance system operations,
7. evaluate and develop methods of control, (manual, automatic or system),
8. speed planning and design processes,
9. increase agricultural productivity by improving water delivery service to farmers, and
10. improve training opportunities concerning irrigation conveyance system function and operations.

Considerations in the Development of the ICSS Model

The ICSS Model was designed to simulate the hydraulics, operation and hydrology of irrigation conveyance systems as they vary with time in response to changing flows into and out of the system and varying internal and external physical conditions. The model was developed such that it could:

1. Consider and/or simulate all controlled and uncontrolled flows within, to and from the system while considering the full range of variation of system physical, operational and hydrologic characteristics using normally accepted hydraulic engineering, irrigation engineering and hydrologic techniques.
2. Simulate relevant field conditions.
3. Use verifiable mathematical theories and methods.
4. Perform all calculations using numerically conservative techniques.
5. Input all relevant information in a form convenient for intended user.
6. Output all relevant information in a form convenient for the intended user.
7. Use a minimum of computer resources while being convenient to use.

Considerable effort was made to establish the scope of the modelling problem being addressed prior to the actual design of the ICSS Model. This culminated in the development of terminology and classification systems for identifying and describing conveyance system configuration, Manz 1987 (a), components, Manz 1987 (b), operations, Manz 1987 (c) and water demand, Manz 1988. It was concluded that though the "ultimate general" model was possible it certainly was not as yet a practical objective. Rather, it was important to develop a model consisting of a relatively small permanent core of subroutines to which subroutines necessary to simulate those conveyance system characteristics immediately under consideration could be readily added or removed, Manz 1990 (a). The rigorous evaluation of the characteristics of irrigation conveyance systems facilitated the design of the permanent core and methods to permit efficient customization. It was intended that the model be able to consider the broadest range of hydraulic, operational and hydrologic characteristics and be able to generate all information required by particular users to meet their performance evaluation needs. The opportunity to provide a wide range of customized model-user interfaces including graphics displays was considered very important to ensure model acceptance.

Intended users could include engineers, technicians, planners or operations personnel from different irrigation projects in different countries, each relating to the same conveyance system, and therefore the model, in a different way independent of the model development team.

Characteristics of the ICSS Model

General

The ICSS Model is capable of simulating, with relatively minor programming effort, all of the important hydraulic and operational characteristics of known types of lined or unlined irrigation canals under steady or unsteady hydraulic conditions. Single canals or networks of canals may be simulated. Canal reaches may be prismatic or non-prismatic. No restrictions, computer resources withstanding, are placed on the number or type of canals or hydraulic structures considered.

Subroutines have been developed which simulate the hydraulics and operation of:

- manually operated radial gate turnouts with free outlet,
- manually operated radial gate check structures with free outlet,
- manually operated overshot pivoting-weir type check structures operating with free, submerged or alternating free and submerged outlet,
- automatically operated overshot pivoting-weir check structures operating with free, submerged or alternating free and submerged outlet,
- combination of manually operated radial gate and overshot check structures with free outlets,
- manually operated flash-board check structures with free outlet,
- manually operated orifice-type turnouts (rectangular, circular, radial gate)
- automatically and manually operated pump-type turnouts,
- combined automatically and manually operated pumps,
- uncontrolled stormwater inflow with pre-established hydrograph characteristics,
- controlled positive inflow,
- expansion structures,
- contraction structures,
- bridges,
- vertical or chute type drop structures,
- minor channel change or extension,
- regulation ponds,
- automatically operated emergency diversions,
- automatically operated inlet structures,
- siphons,
- single and multi-bay Egyptian fahmi type turnouts,
- Egyptian fteel turnouts,
- weirs (misc. types)
- manually operated multi-bay sluice gate type regulators operating under free, submerged or alternating free and submerged outlet with or without navigation locks,

- inflow hydrographs,
- in channel rating curves and
- combined automatically and manually operated multi-bay sluice gate type reservoir outlet structures.

Canal characteristics such as shape, roughness, slope, seepage, precipitation inflow and other distributed lateral inflows or outflows may each be varied along the canal length as frequently as required. Canal cross-section may be trapezoidal, rectangular, circular, parabolic or irregular in shape. Continuous function or table data may be used.

Reservoir characteristics may be described using elevation storage data in the form of continuous functions or table data.

The hydraulic characteristics of inlet and outlet structures may be described using continuous function or in the form of tables.

The model is capable of accommodating several different subroutines to describe temporal or spatial changes in channel roughness or each of the various distributed lateral in/outflow components. The model is executed, (run), interactively with required output displayed at the terminal and/or stored on disk for future consideration.

Output from the ICSS Model may include the following information:

- a restatement of input data;
- the initial water surface profiles, velocities and discharge throughout and at prescribed locations within each reach;
- the water surface profiles and velocities, as they vary with time and at prescribed locations within each reach;
- the water depth and discharge, as they vary with time, at the inlet and outlet of each reach;
- instantaneous and cumulative statement of the water balance for each reach including:
    - the discharge at the beginning and end of each reach,
    - the rate of useful water delivery to farms,
    - the storage in reach,
    - the rate of seepage and evaporation loss,
    - the rate of precipitation gain, or other distributed lateral inflows or outflows,
    - the cumulative volume of inflow to and flow at end of reach (not to be confused with flow out of reach),
    - the cumulative volume of useful farm water delivery,
    - the cumulative volume of seepage and evaporation losses from reach,

  - the cumulative volume of precipitation gains to reach,
  - the cumulative volume of other distributed lateral inflow or outflow to or from reach, and
  - the cumulative volume of useful flow to downstream reach;
- a record of all operations performed on the hydraulic structures bounding each reach;
- a record of the hydraulic structure physical status and flow conditions at the inlet and outlet of each reach; and
- a performance summary for entire simulation.

The output may be different for each reach. The output is modified and/or presented as required to suit user needs. The structure of the ICSS Model permits convenient interfacing with virtually all commercially available graphics, spreadsheet and program management software for use on IBM 386 and 486 computers and compatibles.

The steady flow simulation capability of the ICSS Model is achieved using the equations for gradually varied flow as derived and discussed by Henderson 1966 and modified to consider non-prismatic channel sections as shown below. These equations are solved using a finite difference technique similar to that introduced by Fread and Harbaugh 1971.

$$\frac{d_y}{d_x} = [S_o - S_f - \frac{2Q}{gA^2}p + \frac{1}{Ag}\left(\frac{Q^2}{A^2}\right) A_x^y] / (1 - F^2) \qquad \textbf{(1)}$$

$$\frac{d_y}{d_x} = [S_o - S_f - \frac{Q}{gA^2}i + \frac{1}{Ag}\left(\frac{Q^2}{A^2}\right) A_x^y] / (1 - F^2) \qquad \textbf{(2)}$$

where Q = rate of flow in channel;
p = rate of distributed lateral inflow;
i = rate of distributed lateral outflow;
y = channel depth;
x = distance along channel;
A = cross-sectional area of channel;
F = Froude number;
g = acceleration due to gravity;
A_x^y = rate of change of area with respect to x,y = constant;
S_o = slope of channel bottom; and
S_f = slope of total energy line as defined by the Manning equation, written as:

$$Q = A/n \; R^{2/3} \; S_f^{1/2} \qquad \textbf{(3)}$$

where n = hydraulic roughness; and
R = hydraulic radius.

The unsteady flow simulation capability of the model is achieved through the solution of the equations of unsteady, gradually varying, open channel flow, (the St. Venant Equations), as derived and discussed by several authors including Strelkoff (1969). The forms of these equations used in the ICSS Model are as shown below:

$$\left(\frac{A}{B}\right) \frac{\partial V}{\partial x} + V \frac{\partial y}{\partial x} + \frac{\partial y}{\partial t} + \frac{V}{B} (A_x^y) - \frac{1}{B} (p-i) = 0 \tag{4}$$

$$\frac{\partial V}{\partial t} + V \frac{\partial V}{\partial x} + \frac{\partial v}{\partial x} + g(S_f - S_o) + \frac{V}{A} (p-i) = 0 \tag{5}$$

where B = width of free surface of water;
V = average velocity of water; and
t = time.

These equations are solved using the weighted 4-point implicit finite difference technique described by Amein 1968 and demonstrated by Amein and Fang 1970.

Computational Characteristics

The accuracy, conservation, convergence and stability characteristics of the weighted four point implicit technique used to solve the unsteady flow routing equations have been thoroughly investigated, El Maawy 1991. Criteria for ensuring convergence and stability need to be established for the extremes of flow variation prior to model application and may be different for each reach of an individual canal or for each canal in a network. This process is not difficult consisting only of experimenting with various computational time and distance intervals prior to model commissioning. Computational time intervals may vary with canal within a network. The only restriction is that the time intervals used must be in even multiples of the next smallest time interval, (usually the smallest time intervals are used with the smallest canal). The distance intervals used may vary with reach. The distance intervals within each reach may be varied throughout the reach as required, (eg. Small intervals are useful near downstream brinks but much larger intervals may be used a short distance upstream of the brink). The weighing factor may also be varied but is normally kept constant at 0.55 to maximize solution accuracy. Once suitable computational time and distance intervals have been established, the model can be expected to be accurate, conservative, stable and convergent over the full range of hydraulic, operational and hydrologic characteristics to be considered. The larger the time and distance interval used the more rapid the simulations can be expected to proceed.

The routing routines presently used by the ICSS model cannot exactly simulate the filling of a completely dry canal or the complete emptying of a canal. These capabilities are provided for by allowing minimum depth or flow conditions to be specified for individual reaches as required.

Boundary Conditions

No restrictions are placed on the hydraulic and operational characteristics of the hydraulic control structures considered by the model for application to either single canals or networks of canals. For example, control structures such as radial gate check structures operating under free outlet, submerged or alternating outlet conditions may be modelled. The ICSS Model automatically groups reaches into pools such that both the upstream and downstream boundaries of the pool permit a closed solution of the unsteady flow equations at the same time step. The minimum number of pools considered per canal is one (any number of reaches). The maximum number of pools is equal to the number of reaches in the canal. Operations may be fixed, manual or automatic or some combination of these methods. Control may be local or system control or some combination of local and system control. The model-user interface describing user relationship to hydraulic control structures may be tailored to exactly suit user needs. (eg. information provided such as depth, flowrate, structure adjustment, emergency operations, use of imperial units or even another language.)

The equations used to describe the flow through hydraulic control structures are taken from available literature and are normally the same as those used for design.

Hydrological Considerations

Recall the equations to compute both steady and unsteady flow conditions incorporate the ability to consider distributed lateral inflow or outflow, (eg. precipitation or seepage). The magnitude of these quantities are controlled by subroutines which employ algorithms specified by the user and incorporated into the model. Algorithms used may employ functions in which in canal flow conditions and/or time are the independent variables. The characteristics of distributed lateral inflow or outflow may vary with each reach.

Network Considerations

The network version of the ICSS Model, ICSS 4, requires that the sequence in which unsteady flow computations are performed for each canal be specified. Typically, the computations are performed starting with the most upstream canal. Computations then proceed canal by canal in the downstream direction. Computations proceed in the opposite direction in the steady flow calculation procedure used during model initialization.

Since canals in networks tend to reduce in size and capacity in the downstream direction provision is made to decrease the computational time interval as required and described previously. The simulation of canals throughout the entire network can be expected to have similar accuracy, conservation, convergence and stability characteristics. (Hydraulics of larger canals can normally be simulated using larger computational time intervals.)

Model Input

It is important to note that the ICSS Model normally requires exactly the same information as that used for the design of the canals and their associated hydraulic control structures. The data used would be familiar to irrigation and hydraulic engineers and may even be taken from as-built reports. The quality of the simulations can be expected to correlate well with the quality of input data. Sufficiently accurate data can be used to produce reliable simulations. Preprocessors are used to facilitate data input and editing.

Restart Option

The restart option allows the user to stop a simulation at any time, store relevant information, and continue the same simulation at some later time. This has been found to be a very useful capability. Users may experiment with a variety of operational or management strategies starting from a common unsteady flow condition.

Computer Requirements

Any version of the ICSS Model may be run on an IBM 386 computer with math coprocessor or IBM 486 computer. Versions of the model are presently being used with desk and portable computers. The model is being used with DOS and UNIX operating systems.

Model Verification

The steady and unsteady flow routing techniques have been verified using high quality laboratory data collected by Treske 1980. The data and the methods used to obtain it have been critically examined and found satisfactory by the Canadian Society for Civil Engineering Task Committee on River Models 1990 in its program to evaluate river simulation models. The flume used was made of concrete, rectangular in cross-section, 1.25 m wide and 210 m between inlet and outlet measurement stations. The longitudinal slope of the flume was 0.0019 and the roughness coefficient; as described by Manning's n was 0.0120. A rating curve at the flume outlet is defined by the relation:

$$y_{ds} = 1.344\ Q_{ds} + 0.08656 \tag{6}$$

where y_{ds} and Q_{ds} are the depth and discharge at the downstream boundary respectively. Measured stages and discharge at the upstream and downstream stations as reported by Treske are listed in Appendix III.

A comparison of the predicted discharge and depth at the downstream boundary and depth at the upstream boundary from an appropriately configured version of the ICSS Model and Treske's experimental observations are shown in Figure 1, 2 and 3.

The ICSS Model under predicted the peak depth and discharge at the downstream boundary by 0.29 and 1.9 percent respectively and the peak depth at the upstream boundary by 0.68%. The predicted hydrographs exhibited no error in phase shift, the difference between time to peak of the inflow hydrograph and time to peak of the downstream hydrographs. The hydraulics of the various boundaries are modelled as accurately as the information and theories available in the literature or provided by clients.

Experience with ICSS Model

The ICSS Model has been successfully applied to several consulting and research projects in Canada and Egypt. These include:

1. A study of the control of irrigation return flow from canals typical of southern Alberta, and a sensitivity analysis of physical and operational factors which contribute to both surface and subsurface return flow, Manz and Lipowska 1988 and Manz 1990 (b).

2. Evaluation of the impact of aquatic weeds on the performance of irrigation conveyance systems, Manz and Westhoff 1988.

3. Impact of uncontrolled urban storm-water inflow on the operation of irrigation main canal systems, Manz and Ratnayake 1987.

4. Several short courses to personnel responsible for the operation and maintenance of irrigation conveyance systems in southern Albert and Indonesia. (The trainees interacted with the program which was set up to simulate the operation of canals similar to those the trainees would eventually operate.)

5. Evaluation of the operation of the St. Mary River Irrigation District Main canal between Stafford Reservoir and Horsefly Check, 45 km, 41 cumec capacity, earthlined, 71 turnouts, 40 drainage inlets, 22 bridges and 3 check structures, Manz

1991 (b).

6. Evaluation of automatically operated overshot pivoting-weir type check structures, Schaalje 1991 and Schaalje and Manz 1992.

7. Simulation of Western Irrigation District Main Canal, Calgary to Chestermere Lake - 25 km, 45 cumec capacity, earthlined, automatically operated inlet, overshot check, two emergency radial gate spillways, any number of storm water outfalls drain into canal - terminates in chute-drop structures, consulting project completed September 1991, report in review process.

8. Simulation of Eastern Irrigation District Lateral J system and sublateral systems individually and combined -approximately 2 cumec capacity lined and unlined main canal, 8 sublaterals, (two of which have additional sublaterals), approximately 110 diversion, check, drop and culvert type structures - model to be used for training and the evaluation and development of operational procedures consulting project, Manz 1991 (c).

9. Calibration and verification of steady and unsteady flow open channel hydraulic models, El Maawy 1991.

10. Developments of field calibration and verification procedures continuing research project.

11. Development and evaluation of methodology to simulate atypical or unusual canal hydraulics such as steep surges for inclusion in the ICSS Model, continuing research project.

12. Simulation of main canal subsystem in Nile River Delta irrigation project, Egypt. Project includes approximately 80 km of canal of 80 cumec capacity. Hydraulic structures modelled included multi-bay regulators with navigation locks, fteel turnouts and fahmi gates. Model is being used as part of automation and control of canal system. Consulting project funded by the Canadian International Development Agency, Metzger et al. 1992.

13. Optimization of irrigation conveyance system operations, Lin 1991 and Lin and Manz 1992. This research is still in progress.

14. Simulation of main canal, reservoir, and power house system in the St. Mary River. Irrigation District, Alberta, Canada. Project includes 25 km of main canal of 70 cumec capacity, 3 reservoirs, power canal, power plant, automatically operated sluice gate type reservoir outlet structure, three automatically operated overshot check structures, (automation is in upstream and downstream control.), and a 6 km non-prismatic irregular channel section. Consulting project to be completed by September 30, 1992.

15. Several versions of the Model are used to train graduate students on the operation and management of irrigation conveyance systems at the University of Calgary. Graduate students are trained to modify and configure the ICSS Model for use in their research projects.

Experience with the model indicates that there are usually fifteen to twenty frequently used types of structures within a particular region which need to be simulated. Once the necessary subroutines are developed, modeling of virtually any canal in the region becomes quite a simple process, specific user needs withstanding. It is also important to note that even widely separated regions will employ many of the same type of structures which reduces the modeling problem still further.

Because of the modular design of the ICSS Model, development of the subroutines necessary to describe the hydraulics and operation of individual structures is a relatively well defined and straight forward process. The development procedure includes: structure description, identification and description of hydraulic characteristics, identification and description of operational characteristics, numerical representation of hydraulic characteristics, computer code development and commissioning of software. The latter three steps require between two to six normal working days to accomplish depending on the complexity of the structure hydraulics and/or operational characteristics. Users have the opportunity to clearly specify the features they want, particularly the model-user interface, and expect the model development costs to not only be affordable but also be economical.

Because the various versions of the ICSS Model are developed in close collaboration with intended users, training in the use of a properly configured model rarely requires more than a few hours. Training to configure a particular version of a model normally requires one to two days.

Summary and Conclusions

Experience with the ICSS Model has demonstrated that it can achieve the rapid development, evaluation and introduction of new technology and practices as is urgently required to achieve sustainability. Specifically the ICSS Model has been used in field and research applications to evaluate the performance of existing and proposed systems; develop and introduce innovative designs and operational and management strategies; assess, develop and introduce appropriate rehabilitation and maintenance programs; and train personnel associated with irrigation projects, particularly the conveyance systems.

The computer modelling technology employed within the ICSS Model is based on previously developed and verified theory and standard hydraulic engineering practice. The design of the model, however, is unique.

The Irrigation Conveyance System Simulation (ICSS) Model successfully simulates the hydraulics, hydrology and operation of open channel irrigation conveyance systems, (single canals or networks), as required by irrigation engineers, managers, planners and operators. The model was designed such that it could be efficiently customized to suit individual user needs. All known types and variations of hydraulic control structures, (fixed or manually and/or automatically operated), may be simulated. Hydraulic structures may be locally or system controlled.

Canals may be simulated as they vary in the field; that is, lined or unlined, variable seepage etc. The algorithms used to simulate the steady and unsteady flow have been verified using high quality experimental data obtained by Treske 1980. The hydraulics of individual control structures are simulated using algorithms similar to those normally used by irrigation and hydraulic engineers during the design process. A properly configured version of the ICSS Model can be expected to be robust over the full range of individual user applications without significant or unknown compromises in the integrity of the hydraulic and hydrologic computations.

Model-user interfaces, as they pertain to data input, communication between user and model during the simulation process, user control during the simulation process, data generation, processing and management during the simulation process and post simulation data management are designed to suit user needs or may be independently added or modified by the user. The complexity of these interfaces may vary depending on the intended users objectives, technical background, knowledge of irrigation project management, familiarity with computers and programming, time constraints and budget. Manuals and user training vary accordingly. Models are normally used independently of developer.

Acknowledgements

The author would like to thank the Department of Environment, Government of Alberta and the National Science and Engineering Research Council of Canada for funding much of the research leading to the development of the ICSS Model. Thanks also goes to the many farmers, canal operators, technical staff and management of the irrigation districts in southern Alberta, the Canadian International Development Agency and several Canadian consulting engineering firms for directly and indirectly providing considerable support and the critical review needed for the model development process.

Appendix I - References

Amein, M., 1968. An implicit method for numerical flood routing. Water Resour. Res. 4(4), pp. 719-726.

Amein, M. and Fang, C.S., 1970. Implicit flood routing in natural channels. Hydraul. Div. ASCE, December 1970, pp. 2481-2500.

Amorocho, J. and Strelkoff, T., 1965. Hydraulic transients in the California Aqueduct. Water Science and Engineering Paper 1008. Department of Water Science and Engineering, University of California, Davis, California, June 1965.

The Canadian Society for Civil Engineering Task Committee on River Models, 1990. Comparative evaluation of river models, Vol. V of the Proceedings of the Annual Conference of the CSCE, May 1990, Hamilton, Ontario, Canada, pp. 282-300.

El-Maawy, A.A., 1991. Weighted Four-Point Implicit Method of Solution of the St. Venant Equations, thesis as part of the requirements for Master of Science in Civil Engineering, University of Calgary, Calgary, Alberta, Canada, pp. 143.

Fread, D.L. and Harbaugh, T.E., 1971. Open-channel flow profiles by Newton's iteration technique. J. Hydrol. 13, pp. 70-80.

Henderson, F.M., 1966. Open Channel Flow. Macmillan Publishing Co., New York, pp. 522.

Hennessy, J., 1991. Irrigation water management in Afro-Asian Countries, Keynote Address, Afro Asian Regional Conference, November 1991, Bangkok, Thailand, pp. 1-18.

IIMI 1988. Hydraulic modeling of a main canal system: the next best thing to buying a canal, International Irrigation Management Institute, (IIMI) Review, Vol. 2, No. 2, Aug. 1988, pp. 18-20.

Le Moigne, G., Barghouti, S. and Plusquellea, H., editors 1988. Technological and

Institutional Innovation in Irrigation, World Bank Technical Paper No. 44, Proceedings of workshop at World Bank, April 5-7, 1988, World Bank, Washington, D.C.

Lin, Z. 1991. Optimum operation of irrigation canal systems, thesis as part of the requirements for Master of Science in Civil Engineering, University of Calgary, Calgary, Alberta, Canada, pp. 147.

Lin, Z., and Manz, D.H., 1992. Optimal operation of irrigation canal systems using nonlinear programming - dynamic simulation model, International seminar on the application of Mathematical Modelling for the Improvement of Irrigation Canal Operations, 26-29 Oct., 1992, Montpellier, France.

Manz, D.H., 1985. Systems Analysis of Irrigation Conveyance Systems, thesis as part of the requirements of Doctor of Philosophy in Civil Engineering, University of Alberta, Edmonton, Alberta, Canada, pp. 435.

Manz, D.H., 1987(a). Terminology for describing irrigation conveyance systems, Journal of Irrigation and Drainage Engineering, ASCE, Vol. 113, No. 2, May 1987, pp. 142-154.

Manz, D.H., 1987(b). Classification of irrigation conveyance system components, Journal of Irrigation and Drainage Engineering, ASCE, Vol. 113, No. 4, Nov. 1987, pp. 479-496.

Manz, D.H., 1987(c). Classification and description of the methods used to operate irrigation conveyance systems, Canadian Water Resources Journal, Vol. 12, No. 1, 1987, pp. 89-96.

Manz, D.H., 1988. Terminology for describing on-farm irrigation water demands, Journal of Irrigation and Drainage Engineering, ASCE, Vol. 114, No. 2, May 1988, pp. 353-358.

Manz, D.H., 1990(a). Systems analysis of irrigation conveyance systems, Proceedings of the International Symposium on Water Resources Systems Application, Department of Civil Engineering, University of Manitoba, June 12-15, Winnipeg, Canada, pp. 388-400.

Manz, D.H., 1990(b). Use of the ICSS Model for prediction of conveyance system operational characteristics, Transactions of the Fourteenth International Congress on Irrigation and Drainage, Rio de Janeiro, Brazil, Volume 1-D, Symposium, pp. 1-18.

Manz, D.H., 1991(a). Performance evaluation of irrigation conveyance systems using dynamic simulation models, Proceedings of International Seminar on Efficient Water Use, organized by Mexican National Water Commission, Mexican Institute of Water Technology and the International Water Resources Assoc., October 1991, Mexico City, pp. 277-284.

Manz, D.H., 1991(b). Computer simulation of the St. Mary's River Irrigation District main canal, Eighth Afro-Asian Regional Conference of the International Commission on Irrigation and Drainage, Bangkok, November 1991, in-press.

Manz, D.H., 1991(c). Eastern Irrigation District water delivery management/operation improvement project. Proceedings of the Technical Session of the 42nd EIC Meeting of the International Commission on Irrigation and Drainage, Beijing, April 1991, pp. 147-157.

Manz, D.H. and Ratnayake, N., 1987. Impact of uncontrolled urban stormwater inflow on the operation of irrigation main canal systems, International Union of Geodesy and Geophysics, Proceedings of the Nineteenth General Assembly, Vancouver, Canada, pp. 15-25.

Manz, D.H. and Lipowska, E., 1988. Control of Irrigation Return Flow in Southern Alberta, a research report for the Research Management Division of Alberta Environment, pp. 210.

Manz, D.H. and Schaalje, M., 1990. Irrigation conveyance system simulation of the El Bahr - El Saghir Canal System, The Daqahliya Governate, Egypt, a restricted circulation manual prepared for the Government of Egypt and the Canadian International Development Agency, prepared through the offices of Sim-Flo Engineering Ltd., Calgary, Alberta, Canada, pp. 540.

Manz, D.H. and Westhoff, D.R., 1988. Effects of aquatic weeds on the performance of irrigation conveyance systems, Canadian Journal of Civil Engineering, Vol. 15, pp. 1-13.

Metzger, J.F., Abu-El-Magd, M., Bakry, M., Ouf, S. and Brichieri-Colombi, J.S.A. 1992. Automation and remote control of a major irrigation canal in Egypt, proceedings of the International Conference on Protection and Development of the Nile and Other Major Rivers, 3-5 February 1992, Cairo, Egypt.

Preissman, A., 1961. Propogation des intumescenses dans les caneaux et rivières, Proceedings of the Frist Congress of the French Association for Computation, Grenoble, France.

Schaalje, M., 1991. A Comparison of Irrigation Upstream Automatic Controllers, thesis as part of the requirements for Master of Engineering in Civil Engineering, University of Calgary, Calgary, Alberta, Canada, pp. 219.

Schaalje, M. and Manz, D.H., 1992. Use of the ICSS Model for the evaluation of automatic controllers for the regulation of irrigation canals, International seminar on the Application of Mathematical Modelling for the Improvement of Irrigation Canal Operations, 26-29 Oct., 1992, Montpellier, France.

Sharma, D.N., Oad, R. and Sampath, R.K., 1991. Performance measure for irrigation water delivery systems, ICID Bulletin, Vol. 40, No. 1, 1991, pp. 21-37.

Strelkoff, Theodor, 1969. One-dimensional equations of open-channel flow, Journal of the Hydraulics Division, ASCE, pp. 861-876.

Treske, A., 1980. Experimentelle Uberpristung numerischer Berechnungsuertatinen von Hochwasserwellen, in Blind: Report of Hydraulics Research Station, Tu Munchen, 44: 1-133.

World Bank/UNDP in Collaboration with IIMI, 1990. Irrigation and Drainage Research, A proposal for an internationally - supported program to enhance research on irrigation and drainage technology in developing countries, Vol. 1, April 1990, World Bank, Washington, D.C.

Appendix II - Notation

A = cross-sectional area of channel
A_x^y = rate of change of area with respect to x,y = constant
B = width of free water surface
F = Froude number
g = acceleration due to gravity
i = rate of distributed lateral outflow
n = hydraulic roughness as defined by Manning's equation
p = rate of distributed lateral inflow
Q = rate of flow in channel
Q_{ds}= rate of flow at downstream boundary of Treske rectangular flume
R = hydraulic radius
S_f = slope of total energy line
S_o = slope of channel bottom
t = time
V = average velocity of water
x = distance along channel
y = channel depth
y_{ds}= channel depth at downstream boundary of Treske rectangular flume.

Appendix III - Treske Data

Measured stage and discharge at the upstream (u.s.) and downstream (d.s.) boundaries of the 210 m long rectangular flume.

Time (min)	U.S. Depth (m)	U.S. Flow (m^3/s)	D.S. Depth (m)	D.S. Flow (m^3/s)
0	0.226	0.103	0.225	0.103
1	0.226	0.103	0.225	0.103
2	0.226	0.103	0.225	0.103
3	0.226	0.103	0.225	0.103
4	0.226	0.103	0.225	0.103
5	0.226	0.103	0.225	0.103
6	0.232	0.111	0.225	0.103
7	0.238	0.124	0.227	0.105
8	0.246	0.134	0.233	0.109
9	0.254	0.146	0.24	0.114
10	0.265	0.157	0.25	0.121
11	0.276	0.17	0.26	0.128
12	0.288	0.183	0.271	0.137
13	0.294	0.186	0.282	0.145
14	0.296	0.175	0.294	0.154

continued

Time (min)	U.S. Depth (m)	U.S. Flow (m^3/s)	D.S. Depth (m)	D.S. Flow (m^3/s)
15	0.296	0.164	0.299	0.158
16	0.295	0.153	0.299	0.156
17	0.293	0.142	0.296	0.156
18	0.287	0.131	0.292	0.153
19	0.278	0.119	0.287	0.149
20	0.269	0.107	0.279	0.143
21	0.265	0.105	0.268	0.134
22	0.261	0.106	0.26	0.128
23	0.256	0.105	0.256	0.125
24	0.251	0.106	0.252	0.122
25	0.247	0.105	0.249	0.12
37	0.23	0.104	0.229	0.106
38	0.23	0.104	0.229	0.106
39	0.229	0.104	0.228	0.105
40	0.229	0.104	0.228	0.105
41	0.228	0.104	0.227	0.105
42	0.227	0.104	0.227	0.105
43	0.227	0.104	0.227	0.105
44	0.227	0.104	0.227	0.105
45	0.227	0.103	0.226	0.104
46	0.227	0.104	0.226	0.104
47	0.227	0.103	0.226	0.104
48	0.227	0.104	0.226	0.104
49	0.227	0.103	0.226	0.104
50	0.227	0.104	0.226	0.104

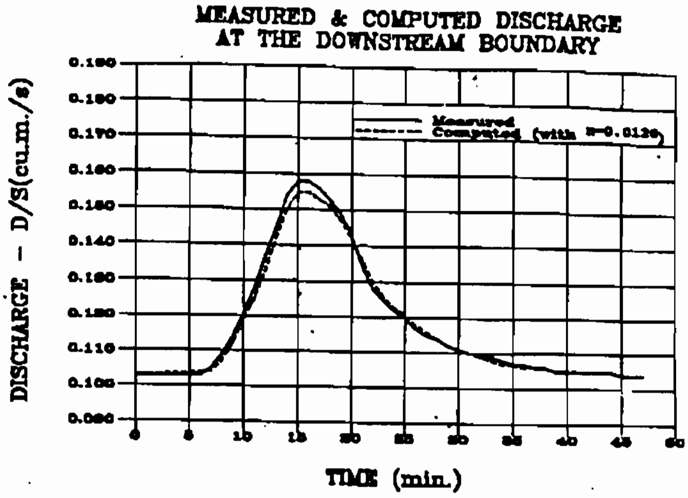

Figure 2. Measured and computed discharge hydrographs at the downstream boundary of Treske's channel.

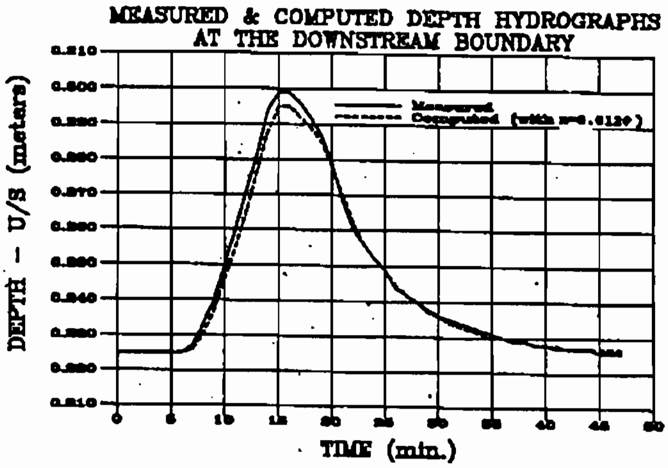

Figure 1. Measured and computed depth hydrographs at the downstream boundary of Treske's channel.

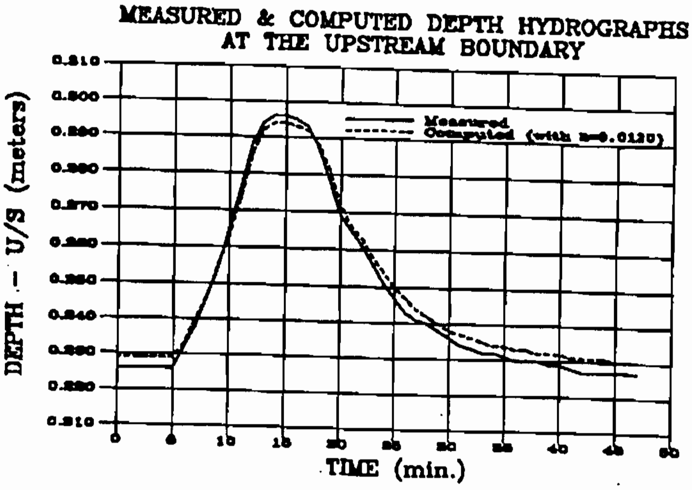

Figure 3. Measured and computed depth hydrographs at the upstream boundary of Treske's channel.