A REVIEW OF IRRIGATION CANAL SIMULATION MODELS AND ITS APPLICATION TO LARGE SCALE IRRIGATION SCHEMES IN SOUTH AFRICA

Olumuyiwa Ojo, Fred Otieno and George Ochieng.

Tshwane University of Technology,

Pretoria, South Africa

Outline

- Introduction..
- Background Equations.
- Consideration.
- Conclusion and Summary.

Introduction

- Irrigation Canal Simulation Models (ICSMs) have become useful and powerful tools for improving efficiency of irrigation water management practices especially at main and secondary Canals system levels. Higher efficiency often translates into increase in command area and crop production. Besides system maintenance and operation of irrigations, ICSMs are tools for conducting research on the hydraulic behaviours of main system level under different management (scenarios). Most models combine efficient numerical algorithms and up-to-date user-friendly interfaces and are developed in close collaboration with the engineers and irrigation managers. It has been already used in many different countries: France, Sri Lanka, Pakistan, Burkina Faso, Mexico, Jordan, Senegal, etc. (Burt and Gartrell, 1991).
- Use of ICSMs assists to a large extent in the centralized control system, in combination with trial and error processes; most often determine efficient canal operational policies. ICSMs can also be used as a tool to modernize large irrigation schemes with the aim of improving their efficiencies. This is because schemes established are not normally operated as per design due to: change of crop pattern, introduction of a new water demanding crop or change in policy which may lead to higher scheme water demand. The alternative is physical redesign and constructions leading to additional investment which often overweigh the cost of acquiring or developing an ICSM.

- ICSMs are representations of physical schemes in computer which can be calibrated to simulate the actual irrigation canal hydraulic and operational conditions. They can also be used to test design modifications, use of different cropping pattern and crop diversification, and to test new operational rules in the schemes.
- In South Africa, there are several large irrigation projects used mainly for irrigation. The conveyance and distribution networks of the projects consist of open canals under manual control. They have been designed to serve large irrigation areas in accordance with collective land use requirements. Nowadays the operational conditions are changed and the irrigation projects exist with problems of inequitable water distribution and high operational losses. The need for improved management of the old canals is recognized and thus provides a good opportunity for the adaptation of ICSMs.
- The paper reviewed the development approach of ICSMs based on key issues and conditions prevalent in irrigation schemes. The paper further reviewed the requirement for ICSMs to be run and a practical uses to the managers of irrigation schemes. The paper also assessed the applicability of the ICSMs to South African (SA) irrigation schemes. Finally, the paper highlighted the existing limitations that would inhibit the adoption of foreign-based ICSMs in SA and argued that local expertise must be exploited to initiate such endeavour.

Background

- **THE REASONS FOR THE USE OF ICSM** Burt and Gartrell (1991) highlighted several uses of ICSM models:
- Real time control:
- Development of control algorithms and operational strategies:
- Canal design:
- Studies of when to release water from a dam to a canal with upstream control:
- Studies of buffer reservoir operation in canal networks, or studies related to buffer reservoir design.

Development Approach of ICSMs

- The flow of water in open channels of irrigation system varies spatially (steady state conditions) and sometimes both spatially and temporally (unsteady sate condition). The two real-life conditions exist whenever open channels are being used to convey water. The two important variables under operating conditions are water level (hydraulic head “h”) and the quantity (volume) of water passing a given point per unit time (discharge “Q”).
- The two major issues, therefore, in simulating flow of irrigation water in a canal which can deliver water in accurate and flexible way are,
- The mathematical concept (equation) that can represent hydraulics of water flow in open canals in steady and unsteady conditions
- The water level control function in the canal that can give the required and flexible discharge Q within the range of h value.
- The first issue can be discussed under governing physical processes assumed in ICSMs while the second issue can be presented under water level control function.

EQUATIONS GOVERNING WATER FLOW IN OPEN CHANNEL

Unsteady Flow Conditions

The equations were derived from laws of conservation of momentum and mass. Amanda (1999) presented a detailed method for deriving these equations. The Q and A form of the equations are: (Othman, 2002):

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial h}{\partial x} + gAS_f - gAS_o = 0$$

$$\frac{\partial h}{\partial t} + \frac{1}{B}\frac{\partial Q}{\partial x} = q$$

There are other forms of saint venant equations in literature (Amanda, 1999).

$$\sum Q_i = \sum Q_o$$

Where "i" denotes for the inflow branches and "o" the outflow branches.

Steady State Flow Conditions

- The steady state condition in an open canal is achieved when the effect of time variation in the water flow becomes negligible.
- spatially varied equations are as expressed :

$$\frac{dQ}{dx} = q_s + Q_L \delta (x - x_L)$$

$$\frac{dh}{dx} = \frac{S_o - S_f - \frac{2\beta Q}{gA^2}(q_s + Q_L \delta (x - x_L))}{1 - \beta \frac{Q^2 B}{gA^3}}$$

Where Q_L = turn out discharge,
β = momentum correction factor which is taken as unity,
$\delta(x-x_L)$ =dirac delta function,
x_L = location of the turnout,
q_s = rate of seepage per unit length,
q_s can be obtained from Wachyan and Ruston (1987) as:

$q_s = Kp$

Continued

$$q_s = Kp$$

Where K = seepage coefficient, p = wetted perimeter. QL is given by Tod et al (1991)

$$Q_L = \sqrt{\frac{2g}{K_L}} A_L w_L \sqrt{h - Z_L}$$

Cont.

- Where KL = total energy loss coefficient with value of 2.5 given by Misra (1996), AL= Area of turn output WL = ratio of turn out opening to turn out area, ZL= down stream reference level.
- The initial stage of developing ICSMs is solving equations (1) to (7). The task of solving these equations required high mathematical skills and good knowledge of computer programming as equations 1, 2, 5, 6, and 7 respectively have no analytical solutions.
- Broadly, there exist three approaches to the solutions of unsteady flow (Saint-Venant) equations. Namely; method of characteristics (Abbot, 1966, Abbot and Verwey 1970), finite difference method (Liggert and Woolhiser 1967, Mishra, 1994, Theodor et al, 1998 and Bautist et al 2003) finite volume method (Amanda, 1999) and finite–element method (Cookey and Moins 1976 and Davis (1976).

Cont.

- **Simulation Canal models**
- The ICSMs can be developed for application in most typical open canal irrigation system through the process described in preceding sections. There are also several software available for use. Some of the available canal hydraulic models software are CANALMAN, DUFLON, CARIMA, MODIS USM and SIC (www.google.com). Each of these models must be calibrated and validated before use as a tool for operational management of an irrigation scheme. Existing simulation models have their positive and negative aspects. The positive aspect is the interest in such models and their usage also model programs are becoming more widely available for use on Personal Computers (PC) and lastly some effective modeling programs exist. The negative part is that these computer programs are not comparable to standard user-friendly PC software. Unsteady canal models with virtually no documentation can provide a very frustrating experience. Canal models, as a rule, have insufficient documentation, require extensive knowledge of programming and hydraulics are cumbersome to manipulate and operate, and have generally been developed for some special circumstance that differs from the new application in just enough ways to be troublesome (Burt and Gartrell, 1991).

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- In order to use ICMSs for a given canal ; it is necessary to have physical and hydraulic data (Othman, 2002). The physical parameters necessary are canal geometry (sample of cross section representing the canal depth, slope, lengths or reaches, off-take from canal), description and dimensions of structures along/across the canal. The hydraulic parameters include the discharge coefficients of the cross structures and off-takes, boundary conditions of the off-takes /tail end of the system, seepage losses and Manning –Stickler coefficients of the selected reaches. Some of these parameters are directly measured from the field , some could be obtained from design specifications while others are adjusted by running the model so that simulated values and measured field values are reasonably close.

Conclusion

- **Advantages of ICSMs**
- ICSMs can give results of the simulation process both in graphical and tabular forms. Water depths and discharges in every section of the simulated canal are provided for a given control action (gate opening, position and opening duration). The results provide for the canal managers with the clear picture of the hydraulic behaviours of all the hydraulic structures and canal reach at both unsteady and steady conditions.
- **Relevances of ICSMS to large Irrigation Schemes**
- Irrigation schemes were established to boost food production. Some of the schemes were constructed without adequate testing and necessary modifications to the design. The causes of the constraints and low performance are many among which are shortage of qualified and experienced staff, insufficient funds for scheme operation and maintenance and insufficient or lack of working materials.

Summary

- The introduction of the ICSMs to South African irrigation schemes may help in addressing operation and maintenance problems. They are valuable aids in development, design and redesign, but they require firm and considerable commitment of time and personnel. Most are not yet considered to be user-friendly for the average engineer. It is expedient and effective to initiate the process of developing a simulation model that can accommodate the level of deterioration of the irrigation schemes in the country. This calls for team work by all experts working in this area. It requires both institutional and personal linkages between Department of Water Affairs, research institutions like CSIR, universities and organizations and experts in selected learning and research centres in developed countries.

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- THANK YOU!!!