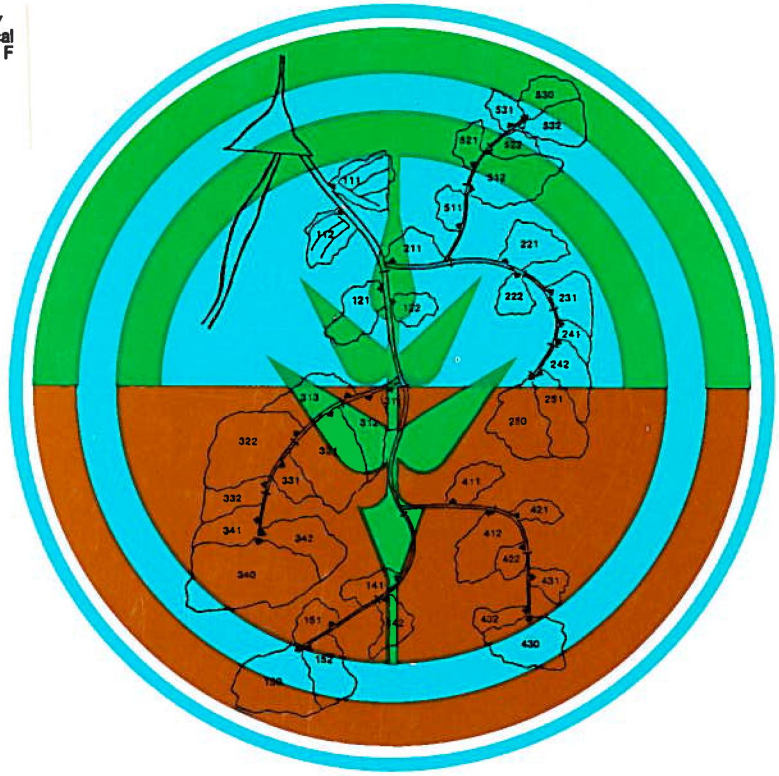

USER'S MANUAL FOR THE FORTRAN VERSION OF USU MAIN SYSTEM HYDRAULIC MODEL

WATER MANAGEMENT SYNTHESIS II PROJECT
WMS REPORT 73

USER'S MANUAL FOR THE FORTRAN VERSION OF USU MAIN SYSTEM HYDRAULIC MODEL

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prepared by

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PREFACE

This study was conducted as part of the Water Management Synthesis II Project, a program funded and assisted by the United States Agency for International Development. Utah State University, Colorado State University, and Cornell University serve as co-lead universities for the project.

The key objective is to provide services in irrigated regions of the world for improving water management practices in the design and operation of existing and future irrigation projects and give guidance for USAID for selecting and implementing development options and investment strategies.

For more information about the Project and any of its services, contact the Water Management Synthesis II Project.

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ACKNOWLEDGEMENTS

The research was a component of the Main Systems Design, Management and Rehabilitation Special Study Topic under the United States Agency for International Development, Water Management Synthesis II Project. I wish to express my appreciation to the WMS Project Management Team for its vision in conceiving the project and its efforts in bringing it to fruition through the Consortium for International Development.

The computer program described in this manual was made possible by the hard work of many people who developed the basic theory on open channel flow to the level it is today. The author is especially grateful to Dr. Wynn R. Walker whose work on surface irrigation modeling forms the basis of this model. I am also indebted to Gary P. Merkley, Dr. Dean Peterson, and many others who directly or indirectly contributed to the success of this work.

FOREWORD

This computer simulation model was developed as part of research studies on development of software required for the planning, design, operation, and maintenance of irrigation systems. This work is an extension of surface irrigation modeling which treated overland flow in furrows, basins, and borders developed by Dr. Wynn R. Walker.

The model is intended to be used as a framework to formulate guidelines for the selection and development of appropriate technology for the operation of the main system. In applying the model to study water conveyance and distribution problems, structural, operational, social, legal, economic, and organizational constraints should be considered. The model can generate a wide range of feasible solutions considering only hydraulic and structural constraints. Out of these technically feasible solutions, an interdisciplinary team can identify socially, financially, operationally, and organizationally acceptable solutions for the improvements of water conveyance and distribution.

The computer program is written in FORTRAN 77. The source code consists of over 8000 lines of optimized code, out of which approximately two-thirds is devoted mainly to improving man-machine interface. This software package is supplied in executable code.

Runtime FORTRAN 77 libraries are supplied by:

Ryan-McFarland Corporation
609 Deep Valley Drive
Rolling Hills Estate, California 90274

A collection of assembly language graphics and input/output handling subroutines are incorporated to extend the capabilities of FORTRAN 77 programming language making it more suitable for interactive simulation. These screen utilities and graphics libraries are supplied by:

Impulse Engineering
P.O. Box 3540
San Francisco, California 94119-3450

This program makes interaction between the user and the computer profoundly simpler thereby enhancing the useability of the software. This is accomplished by taking advantage of interactive simulation capabilities currently available for microcomputers so as to:

1. Minimize data entry error;
2. Present the model output in a form that is easily understood and interpreted; and
3. Improve users' confidence in the software.

No knowledge of open channel hydraulics or computer programing is required to run the program. However, a general understanding of the computer operating system and open channel hydraulics principles and terminology will reduce the learning time, enable the user to take full advantage of the program capabilities and options, and be able to correctly interpret the results.

Copies of the program described in this manual are available from:

Department of Agricultural and Irrigation Engineering
Utah State University
Logan, Utah 84322-4105

Interested parties should specify the disk format on which the program should be sent and whether or not the microcomputer being used is equipped with the 8087 or 80287 math coprocessor.

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ABSTRACT

The performance of canal networks can be improved through physical upgrading of the system and through changes in management and operation. This software provides irrigation professionals and novices with a tool to address issues related to the interaction between design and operation of the conveyance and distribution system.

This manual illustrates the use of the mathematical model which is based on solving the integrated form of Saint Venant's equations to simulate canal filling, operating, and draining phases, bulk lateral outflow or inflow into the section being modeled, and control structure scheduling (gate-stroking) of a branching canal network. The model can be used in evaluating unlimited "What if ..." questions on the planning, design, management, and operational issues.

The software represents a unique set of integrated modules that can be used to better assess the reality in dealing with flow conditions prevailing in canals with the aim of identifying constraints and opportunities to increase manageability of the system. The software highlights are:

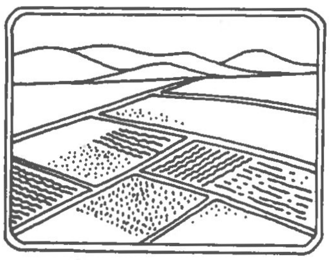
1. The model closely simulates the behavior of existing canal networks making it acceptable by operating staff;

2. The model input, output, and operation meets the needs of different categories of users;

3. The computer program optimizes the computation and memory allocation giving the software the highest possible level of simulation performance on microcomputers; and

4. The computer program has state-of-the-art algorithms and modules that prevent hydraulic simulation errors, numerical instability, and divergence of the solution.

The following pages deliberately depart from WMS II format in order to simplify the material for the potential users.



Management to Improve Performance

INTRODUCTION

Background

The performance of an irrigation water conveyance and distribution system is generally constrained by many factors. The salient ones are:

1. Over-simplistic approaches to planning, design and construction;
2. Rigid approaches to operation and management;
3. Shortage of resources (water, capital, experienced operators); and
4. The socio-economic setup.

Development in system analysis technology has facilitated the development of analytical tools. The Canal Hydraulic Simulation Model (CAHSM) is one such a tool that can augment the operators experience in decision making by:

1. Providing a broader information base on the system operation status;
2. Creating a better understanding of the system and its numerous components;
3. Predicting the consequences of a given course of action; and
4. Selecting the optimal course of action.

The development of CAHSM was spurred by:

1. The current neglect and poor performance of gravity conveyance systems;
2. The complexity and pervasiveness of gravity conveyance systems;
3. The high potential for improvement; and
4. The dire need to answer the question "How can irrigation canal networks be designed, operated and managed to ensure a reliable, adequate and timely delivery of water to the crops?"

The Model

Canal Hydraulic Simulation Model (CAHSM) is public domain software that can be used to evaluate the hydraulic response of the conveyance network to changes in physical and operational features of the system and determine the best combination of controllable parameters to achieve pre-decided system performance goals. This mathematical model is based on solving the integrated form of the Saint Venant equations which describe steady or unsteady, uniform or non-uniform flow regimes of sub-critical flow in open-channels.

The software is capable of mimicking actual hydraulic conditions in a canal network and of technically optimizing the performance of the system by determining the optimal inflow and control structure operation. The model can accurately simulate flow under the following conditions:

1. A branching canal network with a wide range of physical configurations including regulating reservoirs;
2. Submerged and free flow conditions for a wide variety of control structures;
3. Empty canal filling and previously computed hydraulic status or user-specified initial starting conditions;
4. Three operation modes--(a) user-specified inflow hydrograph and control structure settings, (b) control structure scheduling based on demand and upstream flow depth control, and (c) control structure scheduling based on demand and downstream flow rate control.

The operation mode determines the water control strategy to be used. The first is "Operator Decision Control" in which the model user decides on what inflows and control structure settings should be implemented. In the other two options, the program generates the control structure settings that are required to achieve (1) upstream flow depth control and (2) downstream discharge control. In the "Upstream Flow Depth Control", the objective is to minimize flow depth fluctuations in the reach thereby maintaining a constant turnout discharge for a particular structure setting. "Downstream Discharge Control" gives preference to the tail end users. In this case the analysis starts at the downstream end, releasing into last reach a flow rate equal to the sum of all its outflows and systematically working upstream until the system inflow at the headwork is determined. This is done for every time step.

To make the model readily usable in different canal systems, a wide range of water control structures options have been included. Free and submerged flow conditions are considered. For unique structures found in specific projects but not included in the original software, directions on how to write a FORTRAN subroutine and link it with the existing routines will be provided.

A lot of effort has been devoted to the improvement of the man-machine interface. The program is menu driven, it has build in "help" explanation that can be called at any point in the simulation process, traps data entry errors and has a graphical display of input and simulation status at any point. Interactive simulation is provided to enable the user to pause simulation and critically examine the simulation status. Adverse conditions that may develop during simulation can therefore be evaluated and modified just like a canal operator would react in case of a real emergency.

Every computer program requires that the user have some training before he can be expected to use it proficiently. This user's manual for CAHSM (Canal Network Hydraulic Simulation Model) is designed to minimize the learning time. Although the program is complicated, no formal training is required for the program due to the interactive nature of the software and a self-explanatory help menu which can be called at any time.

The model developed represents a unique set of integrated modules that can be used to better assess the reality in dealing with flow conditions prevailing in canals with the aim of identifying constraints and opportunities to increase manageability of the system. CAHSM model highlights are:

1. The model simulates closely the behavior of existing canal networks making it acceptable by operating staff;

2. The model input, output, and operation meets the needs of different categories of users;

3. The computer program optimizes the computation and memory allocation giving the software the highest possible level of simulation performance on microcomputers; and

4. The computer program has state-of-the-art algorithms and modules that prevent hydraulic simulation errors, numerical instability, and divergence of the solution.

Learning Resources

The model's application to: (1) establishing and locating basic improvements to the system; (2) determining points in the system that are sensitive to managerial interference; (3) predicting system behavior; and (4) establishing procedures for better water control are demonstrated (Gichuki, F. N., 1988 and Merkley G. P., 1988). However, successful application of the model requires an integration of hydraulic science and practical skills and knowledge gained during the operation and management to better address broader issues in design, operation, and management of the system.

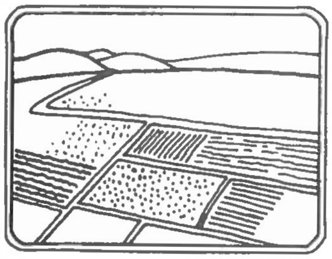
This manual provides complete instructions for using CAHSM but does not attempt to teach the users how to use DOS or the hydraulics of open channel. The following books contain more information of particular subject that may be of interest to potential users.

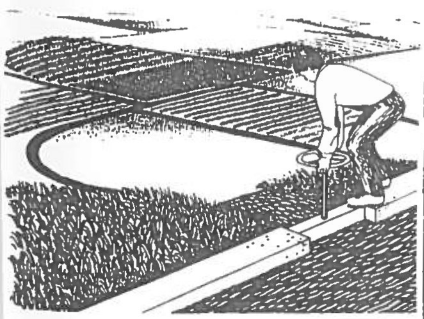
1. Walker W. R. and Skogerboe G. V., 1987. Surface irrigation theory and practice, Prentice hall, NJ.

2. Chow V. T. 1959. Open channel hydraulics, McGraw-Hill Book Company, New York.

3. Gichuki F. N. 1988. Development of a branching canal network model, WMS Report 71.

4. Merkley G. P. 1988. Hydraulic modeling applications in main system management, WMS Report # 74.





THE IRRIGATION WATER CONVEYANCE AND DISTRIBUTION SYSTEM

The irrigation water conveyance sub-system is among the most important components of an irrigation system. To effectively serve its water users, this sub-system should operate so as to deliver the water at the required time, rate, and amount, and minimize operational losses and adverse consequences. To accomplish these objectives, it is necessary to understand how to effectively operate the physical system.

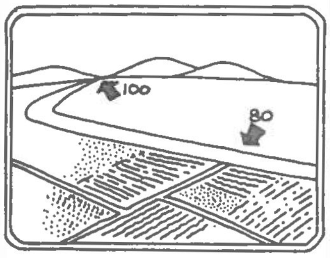
Objectives

Irrigation water conveyance and distribution system performs the task of transporting water from the source and distributing it to various points of use (irrigated land). Canals and pipelines are generally used for this purpose. This manual deals specifically with canal systems. The objectives of canal operators' are to:

1. Deliver water at the specified time, rate, duration and frequency;
2. Minimize operational and seepage losses by closely matching the supply and demand;
3. Minimize the possibilities of adverse effects such as canal overtopping; and
4. Equitably distribute the available water.

The above tasks can only be accomplished if the physical and operational components of the systems is capable of handling the following:

1. Physical system constraints (conveyance time



Water Conveyance Efficiency

lag, capacity, number and location of structures, operability of the structures, etc.);

2. Random changes in demand and supply; and
3. Unauthorized interference with canal flow status (water stealing, vandalism, etc.).

Proper operation of a canal system yields many benefits. The major ones are:

1. Minimizing water use by reducing conveyance and on-farm water losses;
2. Reliable and equitable distribution of water;
3. Saving in pumping power consumption (if applicable), labor and maintenance requirements; and
4. Better response to operational emergencies.

Description of the System

The Physical System

Open-channel conveyance and distribution networks require many different types of structures to effectively and efficiently convey, regulate and measure the canal discharges and also to protect the canal from storm water runoff (Fig. 1). They can be grouped into conveyance, regulation, measurement, protective, and structural components and appurtenance

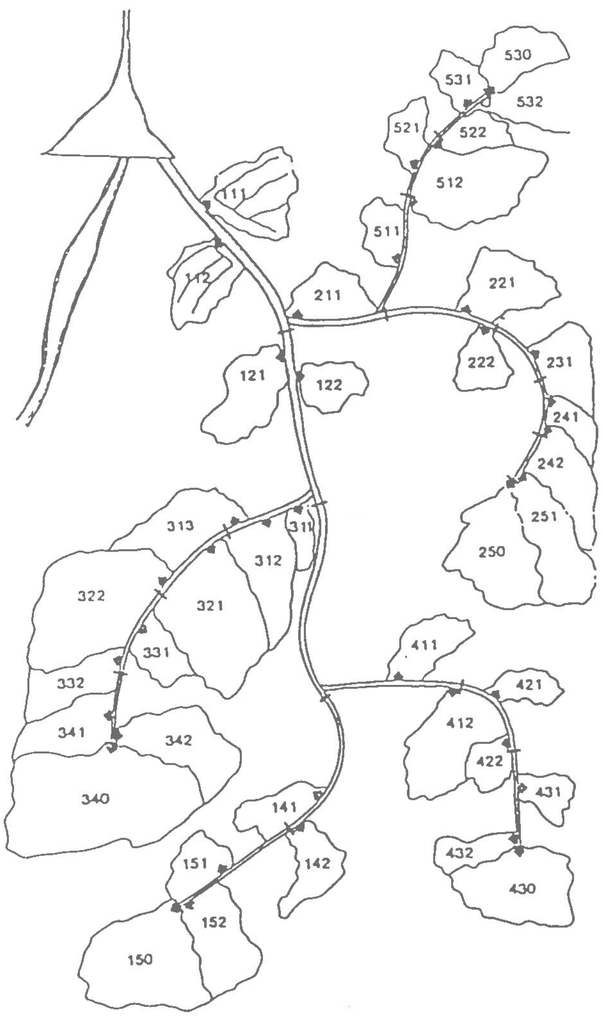


Figure 1. Branching Canal Network Showing Command areas

Table 1. Canal System Hydraulic Structures

Purpose	Structure
Conveyance	Canals, inverted siphons, road crossings, bench flumes, drop structures
Regulating	Headworks, cross-regulators (weirs, gates, etc), pumps, turnouts, diversions, wasteways, regulating reservoirs
Measurement	Flumes, weirs, gates, orifices
Protective	Cross-drainage structures, wasteways
Appurtenances	Transitions, energy dissipators, pipes and pipe appurtenances

For the purposes of flow routing modeling the structures can be divided into two broad categories, conveyance and control structures. Conveyance structures influence the transfer of water from the source to the demand point and establishes the depth, discharge, and reach storage relationships. The principles governing the relationship between depth and discharge depend on the rate of energy dissipation due to friction, the slope of the channel, and the transient nature of the flow. Control structures break the conveyance into discrete reaches. The type, size, and settings of the control structure influences the water surface profile in the reach and determines the relationship between the reach flow conditions and those existing in the downstream reach.

Canal Headworks

Canal headworks is the structure located at the canal intake to control the amount of water entering the canal system. It may be located on a natural river channel or at the reservoir. These structures may be an overflow weir, gated outlet or pumping plant.

Conveyance Features

The main conveyance structure in an open channel conveyance network is the canal. However, because of topographical changes or existing man-made features, other in-line structures may be required. These include:

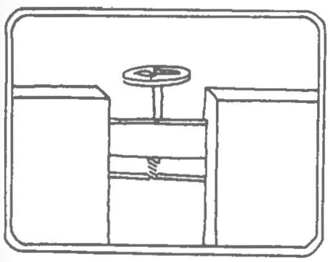
1. Bench flumes to carry water along a steep hillside;
2. Inverted siphons to carry water across natural channels; and
3. Drop or chutes to carry water safely down a hillside.

Reach: A reach is a section of the canal between adjacent structures. The network can be considered as an ensemble of reaches. The lower end of each reach is depicted by the presence of a cross-channel structure or a change in channel geometry, longitudinal slope, channel roughness, seepage losses, or a combination of these characteristics.

Branch: A series of reaches each draining into the downstream reach form a branch. The main branch receives water from the headworks, while the remaining branches are fed by off-takes of upstream branches.

Multiple inlets into a branch are also found where return flow from upstream command areas re-enters the conveyance system.

Pipe Sections: Siphons, culverts and pipe sections are sometimes used in combination with open channel. These structures are normally use to convey water across natural (depression, drainage channel, etc.) or man-made features (roads, railroad, etc.).



Regulating Structures

Regulation structures control the flow of water in the system by regulating the depth and flow rate. They include in-line control structures and turnout structures. The principal structures in this category are gravity flow type (overflow and underflow) and pressurized type (pumps).

In-line control structures: These are main flow regulating structures in the canal system and are use to divide the canal network into manageable hydraulic units called reaches. In-line structure regulate upstream water level and reach outflow.

Turnout structures: Turnout structures divert water from the canal into smaller canals for further conveyance and distribution or directly to the point of use. Wasteways, which divert excess water to prevent overtopping, are included in this category.

Storage facilities: Storage facilities are required for long and short term storage. Long term storage reservoirs store large volumes of water for use during supply shortfalls. Their locations and size is largely dictated by the topography. Supply to the reservoirs is constrained by the available water and canal capacities. Regulating reservoirs provide short term storage for balancing supply and demand thereby minimizing delivery fluctuations associated with difficulties in operating the system. They are operated to ensure that in time the inflow volumes balance the outflow volume and more important that there is sufficient storage capacity to receive rejected deliveries and enough stored water to supply unexpected water demand increase.

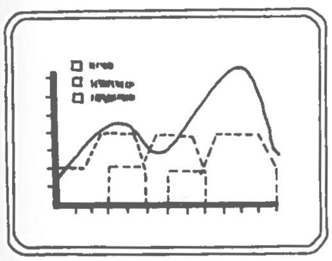
Protective structures are used to externally protect the canal from storm water runoff and internally protect the canal from excess canal flows caused by mis-operation of the canal system or by storm water entering the canal. Only the internally protective structures affect the canal hydraulics. They include side channel spillways, radial gated spillways and siphon spillways.

Energy dissipators are used to dissipate excessive energy acquired by water where velocity is high. They may be impact or hydraulic-jump type. Transitions are used to produce a gradual change in water prism cross-sections and are usually used at structure inlets and outlets and at changes in canal sections. Riprap and gravel protection are used adjacent to structures and at other locations in earth canals where erosion may occur. Tunnels, pipe-sections, and bridges are other miscellaneous structures that may exist in a conveyance system.

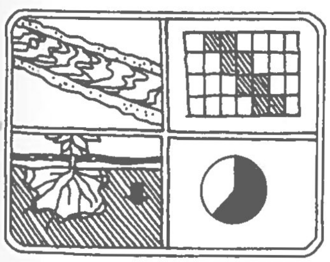
In addition to the conveyance and distribution physical facilities, there is a need for communication infrastructure. These include bicycles, telephones, or computerized systems depending on the degree of water control envisaged.

Organizational Setup

The social and organizational system encompasses the people, individually and in groups, who are involved in the implementation of water delivery plans. They include the staff of the irrigation bureaucracies and those people involved in irrigation activities. The main responsibilities of this system are the establishment of goals, the creation of programs to reach these goals, and supervision of the activities within the program to ensure that the goals will be met.


Water Availability/Crop Selection and Planting

The plans for water deliveries specifies the rules for water allocation and the role of the irrigation bureaucracy. Normally, these plans are based on the design conditions; and, therefore, problems arise when the water supply is less than that for design conditions or when there is a change in cropping pattern. The water delivery rules normally applied are continuous, rotation, on-demand, and combinations thereof.


Flow Rate/Frequency/Depth/Duration

In continuous flow, the emphasis is on physical infrastructure and, therefore, requires minimum communication. It has a higher need of security because the opportunity of water flow interference is high. Rotation systems reduce the chances of interference and depending on the level at which rotation is implemented, increased the level of investment due to increase in channel capacity and control structure. Demand rules have the highest canal capacities requirement and major increase in control structures. Communication between the irrigator and ditch tender is vital, thereby increasing the requirement for co operation and coordination of users and irrigation bureaucracy and a better control of water. This rule is the most flexible.

Because irrigation takes place in environments with significant variability and involves large numbers of people, conflicts are inevitable. These conflicts may arise from water stealing, failure to participate in a maintenance program, etc. A good social-organization system should have the capability to minimize conflicts. This can be achieved by agreement on system objectives and procedures, effective communication at all levels, and an equitable water distribution.

FLOW REGULATION

Hydraulic Concepts

Open channel hydraulics are complicated by the many variable that affect flow conditions. Some of these variables change both spatially and temporally. A wide variety of flow regimes--steady and unsteady, uniform and nonuniform and subcritical, critical and supercritical--that may be encountered further complicate open channel hydraulics.

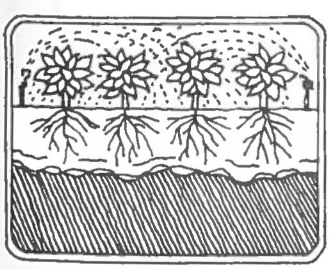
The major variables which govern the flow in canals are:

1. Flow rate;
2. Flow resistance;
3. Longitudinal slope of the channel;
4. Channel cross section geometry and size;
5. Channel losses or gains; and
6. Flow regulation structures.

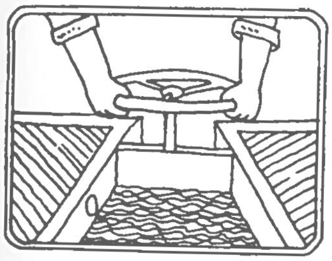
Equations describing the relationship between the above variable will be discussed later in this and other chapters.

Flow in Irrigation Canals

The amount of water demanded by each irrigated plot varies from year to year and depends on the crops grown and stages of growth. Since the aim of irrigation is to supply crops with the right quantity of water at the right time, an ideal main system should be able to control the flow of water so that the supplies match the demands. When operating a canal network, the system operators would like information on the flow rates and flow depths throughout the network along with control structure settings required to

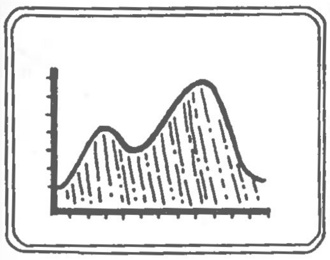


effect the deliveries. This information is required throughout the operation period in order to determine any changes that may be required. Operations are divided into three phases: (1) filling; (2) operating; and (3) draining.



System Operation

Filling Phase: The filling phase starts when water is introduced into an empty reach. During the first time step, a discharge flows into the reach and by the end of the time step, the flow will have advanced some distance along the channel, attained a flow depth sometimes less than an equivalent normal depth, and a certain volume seeps through the wetted perimeter. During a later time step, the water advances an incremental distance while the flow profile in previously defined sections continue to stabilize. If there is a turnout in the reach and the flow depth at the turnout is higher than the turnout sill height, a discharge determined by the stage-discharge relationship of the structure leaves the reach. When the water reaches the end of the reach, it encounters the downstream boundary conditions which then determine the depth and flow at the end of the reach.

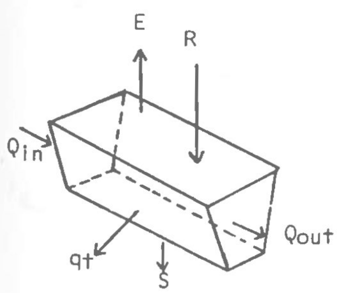


Operation Phase: During the operating phase, flow and depths are managed to satisfy the demands on the system. This is accomplished by changes in system inflow and control structure settings. The stochastic nature of demands creates periods of unsteady, nonuniform flow. Therefore information on how to change from one steady state to another is of particular interest to the system operators. The change must be implemented in a way that minimizes labor, discharge fluctuation, and operational losses. An experienced operator can determine the required inflow into the system and the corresponding control structure settings required to achieve a pre-determined goal. The control structures at the end of the reach are operated such that they release to the lower reaches a flow rate equal to the sum of their turnout demands plus channel losses.

Draining Phase: Draining the canal is of particular interest in systems that have a start-stop operation due to the rotation schedule or periodic system shut-off. In these cases it is important to determine the optimal inflow hydrograph and control structure settings in the sections experiencing shut-off so that the final demands can be met with minimum operational losses. When the water level drops below the turnout or control structure sill height, evaporation and seepage losses determine the residual pool volume when water is re-introduced into the reach.

Governing Equations

When water is introduction into a dry canal, it advances at a rate that is determined by the hydraulic properties of the canal reach (slope, cross sectional geometry and size, channel roughness and channel losses). The rate of advance and flow rate and depth at any point can be predicted mathematically by solving the equations of continuity and motion. To mathematically represent flow in the canal, the canal is divided into control volumes.



$Vol_{in} - Vol_{out} = \Delta Vol$

The continuity equation is based on the principle of conservation of mass and states that the inflow minus outflow equals the change in control volume. For a given time step the equation can be written as:

$$\{\theta[Q_1 - Q_r - q^j]+(1-\theta)\ [Q_k - Q_m - q^{j-1}]\}\delta t/\delta x -$$

$$\{\phi[A_1 - A_k + Z_1 - Z_k]+(1-\phi)[A_r - A_m + Z_r - Z_m]\}= o \quad (1)$$

in which Q = flow across the respective cell boundaries (L^3T^{-1}); A = cross-sectional flow area (L^2); z = infiltrated volume per unit length and is equal to the product of channel losses and wetted perimeter, (L^2); δx = length of the cell (L); δt = time step size in seconds (T); θ = time averaging coefficient to account for the non-linear variation in the flow profile over time (dimensionless); ϕ = time averaging coefficient (dimensionless); k and m subscripts identifying physical parameters at time j-1 for the left and right boundaries of the cell respectively; and l and r are subscripts at the left and right cell boundaries at time j.

The equation of motion is based on Newton's Second Law of Motion. For the control volume, the unbalanced external forces resulting from the interaction of hydrostatic, gravity and friction forces is balanced by the time rate change of momentum. The resulting equation is:

$$\phi[Q_l - Q_k]+(1-\phi)[Q_r - Q_m]\}/g\delta t +$$

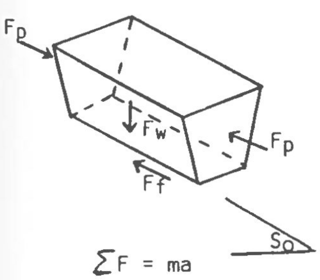
$$\theta\{[P + Q^2/gA]_r - [P + Q^2/gA\}^l\}\delta x +$$

$$(1-\theta)\ \{[P + Q^2/gA]_m - [P + Q^2/gA]_k\}/\delta x -$$

$$S_o\{\theta[\phi A^l = (1-\phi)A_r] + (1-\theta)\ [\phi A_k + (1-\phi)A_m]\} +$$

$$\theta[\phi D_l + (1-\phi)D_r] + (1-\theta)\ [\phi D_k + (1-\phi)D_m] = 0 \qquad (2)$$

where Q = flow across the respective cell boundaries (L^3T^{-1}); A = cross-sectional flow area (L^2); Z = infiltrated volume per unit length (L^2); D = product of area and frictional slope (L^2); P = h_cA (L^3); h_c = vertical distance from water surface to the centroid of the cross-sectional area (L); S_o = longitudinal slope (dimensionless); and g = acceleration due to gravity in (LT^{-2}).



Control Structure Equations: When water reached the end of the reach, it encounters an in-line control structure. The primary purposes of the in-line structure are:

1. Maintain the desired depth upstream of the structure, thereby, establishing an upstream flow profile that is required to provide necessary head on turnout structures located in the reach; and
2. Regulate the flow through the structure in response to changes in demand and supply.

The second type of control structure is the turnout control structure. Turnout structures regulate bulk lateral outflow in the reach and can be located anywhere in the reach.

The control structures have a unique stage-discharge relation that is a function of the discharge coefficient and flow cross sectional area. In irrigation canals, discharge through the control structures can occur as flow under pressure (pumps and underflow structures) or as free surface flow (underflow) or a combination of both. Choice of structures is influenced by the hydraulics of the structure and related flow conditions and the operational requirements. From a hydraulic point of view, the structures selected should minimize flow variation through the turnouts while at the same time meeting the required demands.

The flow regime may be free flow or submerged flow. Free flow, also referred to as modular flow, occur when downstream flow conditions have no effect of discharge through the structure. The equations of discharge cannot be exactly determined due to: (1) variations in flow patterns from one structure to another and from one discharge to another; and (2) the fact that the number of variables involved defy rigorous analytical approach.

The approximate equations generally used are derived from the Bernoulli equation.

Overflow structures include weirs, stop-logs and flow measuring flumes. The equation of discharge over a sharp-crested weir is:

$$Q = C_d W (2g)^{0.5} h_u^{1.5} \qquad (3)$$

where Q = discharge (L^3T^{-1}); C_d = coefficient of discharge that combines the effect of vena contracta, head loss, velocity of approach, and kinetic-energy correction factor in the Bernoulli equation (dimensionless); W = effective crest width (L); h_u = (y - h_s) height of water above the crest in the approach channel (L); y = flow depth in the approach channel (L); h_s = sill height (L); and g = acceleration due to gravity (LT^{-2}).

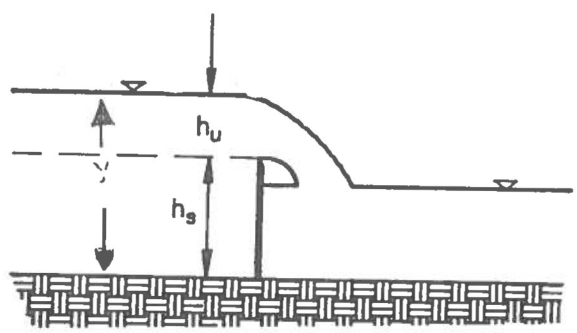


Figure 2. Flow through an Overflow Structure

Any type of opening in which the upstream water level is higher than the top of the opening can be classified as an underflow structure. Underflow structures include orifices, culverts, and gates as illustrated in Fig. 3. The general equations governing flow through an orifice are:

$$Q_f = C_d A(2gh_u)^{0.5} \tag{4}$$

$$Q_s = C_d A[2g(h_u - h_d)]^{0.5} \tag{5}$$

where Q_f = free flow discharge; Q_s = submerged flow discharge; h_d = downstream flow depth; A = b*W, area of the gate (L^2); b = gate opening (L); W = gate width (L); and the other variable are as previously defined.

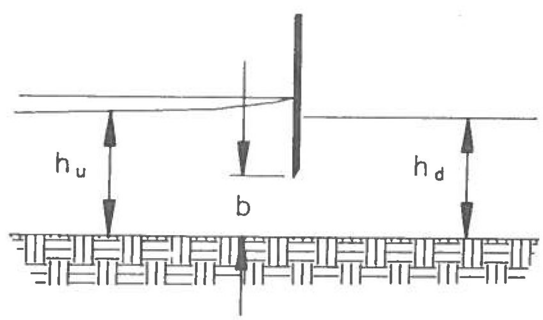


Figure 3. Flow through Orifice Type Structures

Skogerboe et al. (1986) presented general rating formulas based on free flow conditions (Eq. 6):

$$Q = m(h_u)^n \tag{6}$$

where Q = discharge (L^3T^{-1}); h_u = head upstream of the critical section (L); n = flow exponent; m = flow coefficient.

This is equation used for non-standard structures such as culverts, bridges, pumps, etc. For example, when pumping water from a canal, the pump discharge can be considered independent of the canal water flow depth. Thus, for a constant discharge n = 0 and Q = m for $y > h_s$. This allows pump shut down when the water level drops below h_s.

When there is more than one structure controlling the water leaving the reach, it is necessary to define a stage-discharge equation that takes into account the existing combination of structures. The equation of individual structures can be added together such as when a combination of a sluice gate and a weir exists (This option will be incorporate in Version 1.0 of this software).

$$Q = C_{d1}A[2g(h_u-h_d)]^{0.5} + C_{d2}(2g)^{0.5}W(H_2)^{1.5} \tag{7}$$

where the subscripts 1 and 2 identify parameters for the two structures.

Canal Operation Hydraulics

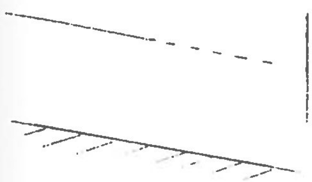
Steady State Operation

Steady state flow conditions occur when there is no change in flow properties with time and can be either uniform or nonuniform.

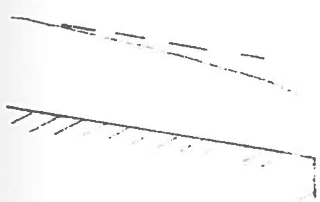
Uniform flow is a hydraulic condition in which the water depth and canal cross section does not change over some section of the reach. This implies that there is no acceleration or deceleration of fluid particles and that the flow depth and the kinetic energy ($V^2/2g$) are constant. Uniform flow is normally established over any long prismatic canal reach with a constant flow. Although, this condition rarely exists in nature due to the spatial variation in canal properties, this assumption provides reasonably good results for most man-made channels. The Manning's equation (Eq. 8) is generally used to evaluate the relationship between discharge and channel properties (normal flow depth, channel roughness, longitudinal slope).

$$Q = \frac{cAR^{2/3}S^{1/2}}{n} \tag{8}$$

where c = units conversion factor and is equal to 1.486 in English units and 1.0 in Metric units; A = flow cross sectional area (L^2); P = wetted perimeter (L); R = A/P, hydraulic radius (L); and n = channel roughness coefficient. Application of this equation is presented in a later section.



<u>Nonuniform flow</u>: In open channel flow the effect of canal slope, channel geometry and size and control structures settings produces a flow with spatially varying velocity and depth resulting from the unbalance between the gravity and frictional forces. This hydraulic condition is called nonuniform flow. If changes in flow conditions occur over a long distance, the flow regime is termed gradually varied flow, otherwise it is rapidly varied flow. Rapidly varied flow hydraulics is beyond the scope of this manual.



Gradually varied flow occur at: (1) the entrances and exits of a canal reach; (2) change in longitudinal slope; (3) change in cross section geometry and/or size and (4) flow control structures. Gradually varied flow conditions are analyzed numerically by applying the energy equation to a control volume. The resulting equation (Eq. 9) relates the change in flow depth to distance along the flow path. The equation governing the gradually varied flow in a prismatic channel and one which includes terms for flow entering or leaving the channel in the x direction is:

$$\frac{dy}{dx} = \frac{S_0 - S_f - \dfrac{Qq^*}{gA^2} - F_q}{1 - F^2} \qquad (9)$$

in which q^* = the lateral flow per unit length (L^2T^{-1});
F_q = 0 for bulk lateral outflow;
F_q = $Qq^*/(2gA^2)$ for seepage outflow; and
F_q = $(v - u)q^*/(gA)$ for bulk inflow;
v = velocity in the main channel (LT^{-1}); and
u = component of velocity in the direction of the main channel flow (LT^{-1}). Other variables are as previously defined.

Unsteady Flow Operation

Unsteady flow conditions exist when flow condition change with time. Unsteady flow operation exists because the actual flow in irrigation canal are made up of a random succession of flow condition changes due to variations in demand and the corresponding control structure operations. Unsteady flow conditions can be initiated by a change in control structure setting which produces flow depth and flow rate changes around it.

Flow conditions at the structure: Figure 5 shows the effect of increasing the gate opening on flow conditions in the upper and lower reaches. Increase in gate opening resulted in flow rate and depth increase at the downstream side and a depth decrease and flow rate increase at the upstream side. Because the discharge through the gate is a function of the head differential, the discharge will momentarily decrease as a result of the decrease in head differential. With the reduction in discharge through the structure, the upstream flow depth will increase and a corresponding increase in discharge initiates. This process is repeated until the flow stabilizes to a new steady state condition.

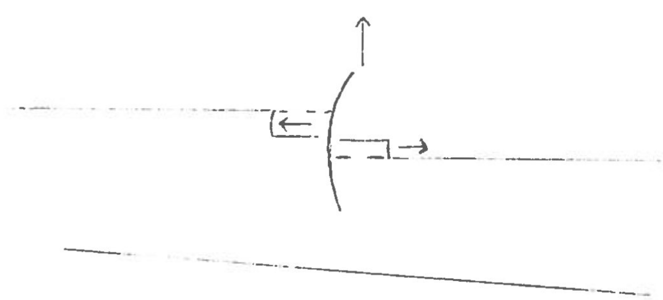


Figure 5. Flow changes due to inline structure operation

Movement of the wave: The gate action and corresponding flow changes discussed above initiates gravity waves that propagates both upstream and downstream. The negative wave (encroachment of lower depth region into one of a higher depth) in the upper reach moves upstream while a positive wave (movement of a higher water front into lower depth region) moves downstream in the lower reach. The height of the wave is attenuated by friction forces as it moves along the reach. The wave velocity is of interest to the canal operator for determining when he should operate the control structures to react to upstream or downstream changes in flow conditions.

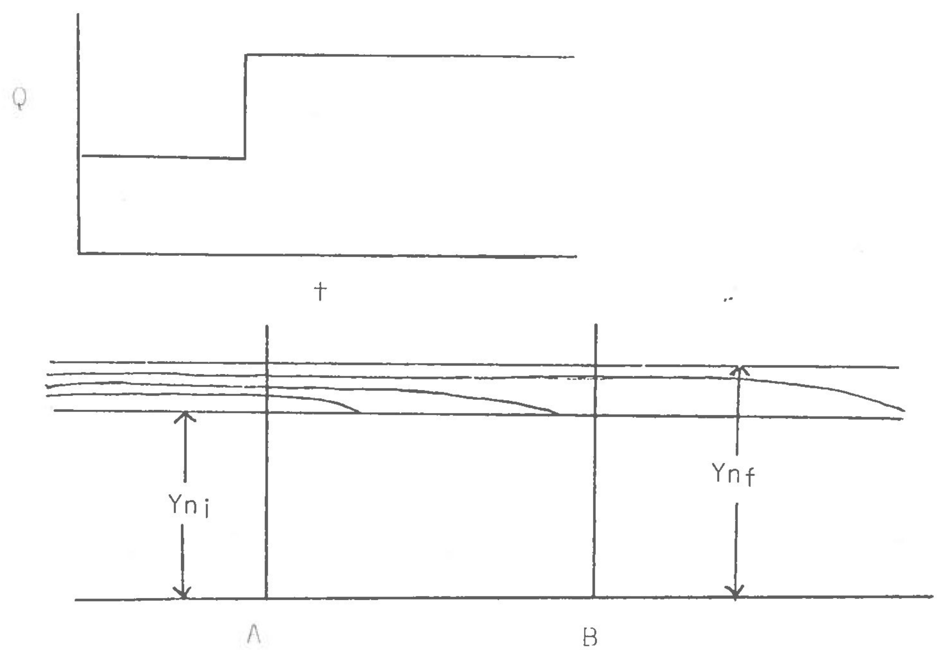


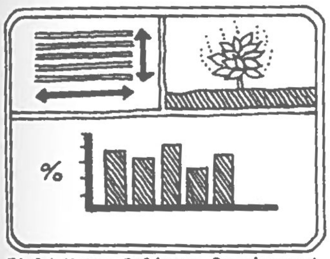
Figure 6. Wave movement

The lower reach experiences a flow rate increase, which for simplicity is show on Fig. 6 as a single step increase in discharge. Figure 6 also shows the transition of flow depth from one steady state condition to another. The flow profiles marked tn shows the movement of the dynamic wave across points A and B.

In the upper reach, the flow depth decreases even though the reach discharge increases. This conditions will occur because the flow depth is higher than the normal depth for that flow rate establishing another steady state gradually varied profile.

Canal Operation Methods

The transfer of water from the source to the point of use is influenced by the delivery and regulation concepts and methods used.



Field Water Delivery Requirement

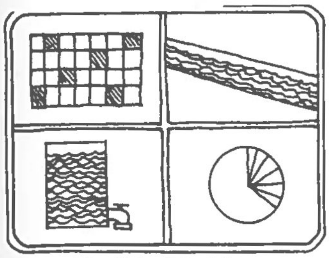
Delivery methods

Water delivery methods establishes the flexibility of a canal system operation and the physical and operational requirements. The major water delivery method are continuous, rotation and on-demand.

Continuous flow: As the name implies, continuous flow concept provides flow on a continuous basis in all conveyance and distribution canals. This concept has the lowest physical and operational requirements but generally has low water use efficiency and flexibility in deliver.

Rotation delivery: The rotation delivery schedule concepts differs from continuous flow in that water is delivered at a larger flow rate for a shorter duration. Irrigators, therefore, take turns in receiving the water. The duration and frequency of rotation may be fixed or variable throughout the irrigation season.

On-demand delivery: Demand delivery concept aims at providing water upon request without an prior notification. It offers maximum flexibility and convenience to the irrigators but creates operational problems associated with random changes in demand.



Flexible Schedules

Scheduled delivery: Scheduled delivery concept combines demand and rotation concepts. Rather than supplying water on a fixed rotation and forcing the users to adhere to that schedule, the users are place their requests in advance and the operating agency tries to meet the demand subject to capacity, time lag and operational constraints in the network. If the demand cannot be met as made, it is modified in time, rate, and/or duration. Scheduled delivery simplifies the operation of the system while at the same time satisfying the water users requests reasonably.

Flow Regulation Methods

The main purposes of open-channel regulation are to:

1. Raise water as high as economically feasible to serve the command area by gravity; and
2. Control water level and discharge so as to minimize turnout flow fluctuations, canal lining deterioration due to changes in hydrostatic pressures, and canal breaching.

Flow regulation can be accomplished by manual or automatic control depending on: the nature of farm water demand; size of the system; availability of funds, electric power, communication systems, and skilled artisans; skill and mobility of canal operators; local traditions and a variety of other cultural and social influences. Over the years, several water control methods have been developed. They are upstream control, downstream control, combination of upstream and downstream control and dynamic regulation.

Upstream Control is the oldest flow regulation method. It aims at maintaining a constant water level upstream of each structure thereby maintaining a constant head on the turnouts in the reach. Figure 5. shows the additional storage required when reach flow rate is increased from Q_1 to Q_2. This additional reach storage is partly responsible for the high time lag in transmission of water. To increase discharge at the lower end, a certain amount of discharge is stored in successive upstream reaches. Conversely, decreasing downstream demand leads to unavoidable losses because decreases in headworks inflows do not have any effect on downstream flows until the water level has dropped to the equilibrium level for that discharge. The response time is a function of flow rate, change in demand, number of control structures, slope of the canal and distance from the source to the demand point.

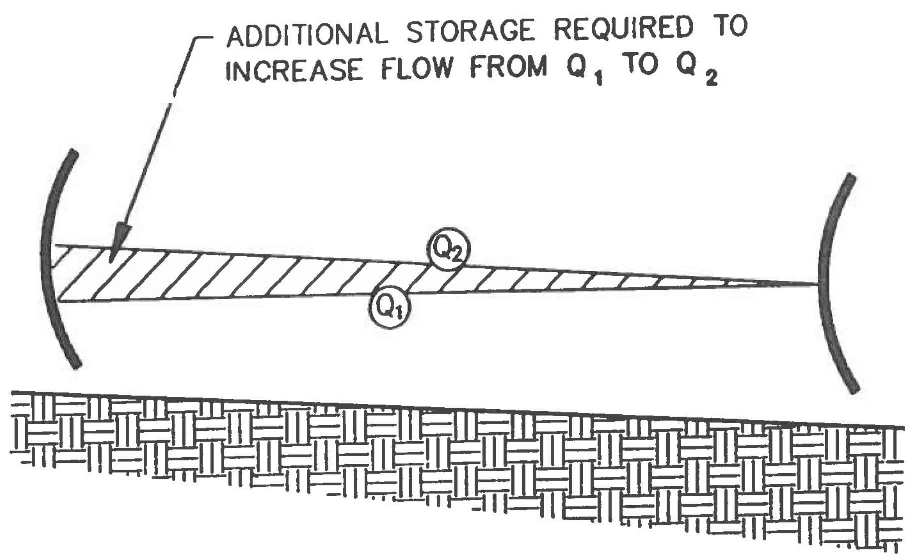


Figure 7. Water surface profile for upstream control

Downstream control facilitates total automation because it allows for control of water levels and also adjustment of flow rates to meet the demand. Downstream controlled systems are equipped with control structures whose settings are controlled by the water level in the downstream reach. Each change in flow depth is transmitted to the upstream gate where corresponding adjustments are made. This step-by-step transmission of change in flow conditions causes the overall supply to the network to be adjusted to suit the demand.

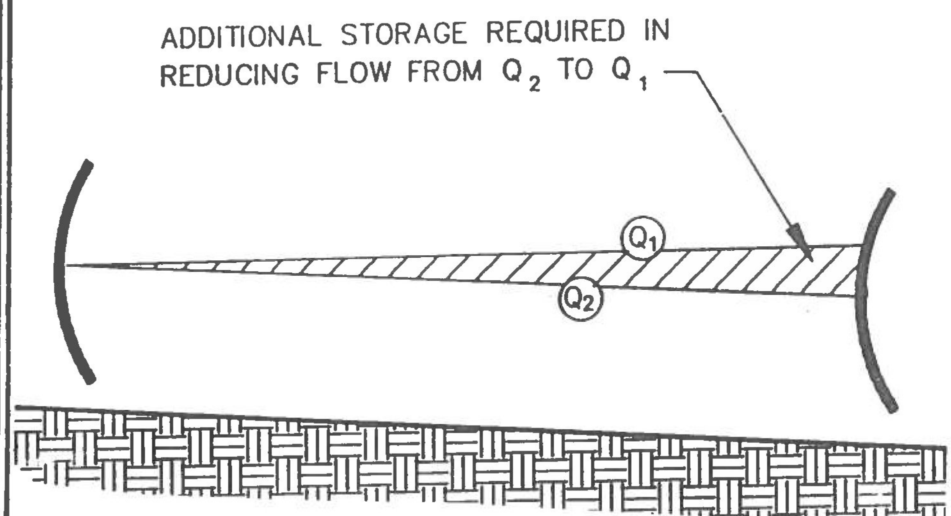


Figure 8. Water surface profile for downstream control

Figure 8 shows the water surface profile when the flow in the reach is decreased from Q_2 to Q_1. It can be observed that the change in flow depth is higher at the downstream end of the reach and therefore level top canals are required. When the demand is reduced no water is wasted because the additional amount that may be added into the reach during the gate closure time is stored in the reach where it remains for subsequent withdrawals.

Dynamic Flow Regulation: In dynamically regulated systems, all the reaches of the canal take place in meeting demands and absorbing the deviations between supply and demand. This is accomplished by simultaneous measurement of water level and control structure settings at various sections in the canal and evaluating and implementing required structural setting adjustments to meet the induced change within the shortest lag time while at the same time minimizing hydraulic transients. Thus, unlike the downstream control which is blind to what happens in other parts of the system except the reach downstream, dynamic regulation is sensitive to flow condition changes throughout the network.

THE COMPUTER MODEL OVERVIEW

Canal Hydraulics Simulation Model (CAHSM), provides the user with sufficient flexibility in the application of the algorithm to simulate the physical and operational characteristics of an irrigation conveyance and distribution system. The mathematical model can be used to determine flow rates and flow cross-sectional areas at all points in the canal network that result from a given physical structure and operational scenario.

General

Modeling Strategy

The principal objective of this study was to develop a model that can be used to evaluate the hydraulic response of the conveyance network to changes in inflow, type and setting of control structures and channel physical features as well as to determine the best combination of controllable parameters to meet predetermined system performance goals. To accomplish the above objectives, theoretically sound simplifying assumptions were made. The simplifying assumptions enabled a mathematical representation of this complex system, and to develop a model that closely approximates the field conditions. In developing the model attempts were made to:

1. Describe the physical processes on a sound theoretical basis so as to make the model readily transferable from one prototype to another;

2. Describe all the system components and their inter-dependencies;

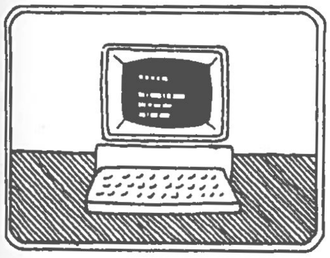
3. Ensure numerical accuracy and stability;

4. Include all phases of main system operation (filling, transient flows and draining);

5. Cater to a wide range of physical configurations and operational scenarios;

6. Achieve rapid execution of the computations and trap as many input and execution errors as possible; and

7. Ensure user-friendliness so that the software can be used by persons with minimal computer, hydraulics, and main system operation skills.



Hardware and Software Requirements

The CAHSM microcomputer program is written in FORTRAN 77 and compiled using Rymn McFarland FORTRAN 77 compiler Version 2.4. Also included are assembly language screen utilities and graphics routines developed by Impulse Engineering.

This program was designed to run on IBM PC/AT compatibles running under the MS-DOS operating system version 2.0 or higher. The software requires a minimum of 512K memory. A hard disk and a 80287 math co-processor are recommended but not required for small systems. A math coprocessor speeds up the program run time. A high resolution color graphics board (EGA or higher) is recommended for users' wanting to take full advantage of the graphic interface. The program will, however, run in a variety of computer monitor environments.

The floppy disks contain the following program and auxiliary files.

CAHSM.EXE - This executable code manages the related programs

CANUTIL.EXE - This program is used to solve for the any unknown in Manning's and control structure equations.

CANDATA.EXE - This executable code manages the project's configuration data

CANGVF.EXE - This executable code compute the gradually varied flow profile for a steady state initial condition.

CANTRAN.EXE - This executable code performs 12-hour simulation of the canal system operation.

CANRES.EXE - This executable code manages the output data from the CANTRAN.EXE program.

The following data files for a test run and demo are included:

RUNFILE
CORNING.CFG
CORNING.INT
CORNING.RFR
CORNING.CSS
CORNING.TSS
CORNING.SUP
CORNING.DEP
CORNING.DMD

Getting Started

This software is intended for use by people with minimal computer and hydraulics background. Thus, a great deal of effort was devoted to improving the user interface. Detailed evaluations and comments of a number of people are incorporated in the final work. Special attention was given to data entry, graphical displays, and interactive simulation. When using a program for the first time, data entry is extremely critical if the user is to get a favorable first impression. Therefore, no effort has been spared in developing user friendly data entry routines. The following requirements for user-friendliness were taken into consideration:

1. Understandable prompts for all communications to the user;

2. Following logical flow of data entry interaction;

3. Use of menu driven commands;

4. Provision of consistent program instructions displayed uniformly throughout the program to avoid confusion; and

5. Scanning all keyed-in information for acceptability to avoid program failure due to non-numeric data entry in place of numeric data or value range error in the model parameters.

To obviate simulation failure due to the user entering non-numeric data when numeric data are called for, data entry routines that analyze each keystroke and discard any non-numeric keystroke were developed. Another possible data input error is entering a value that is out of an acceptable range. For each data item, a minimum and maximum value are displayed and only data in this range are accepted. In an effort to make data entry, editing, and display easier and efficient, graphics have been used extensively. The simulation results are also displayed graphically.

The program is completely menu-driven and very simple to use. The bottom of the screen is devoted to providing the user with operation instructions such as: (1) currently available options; (2) how to move around or enter data; and (3) display error messages.

Driver Program

CAHSM program serves as the driver for all other canal hydraulic simulation programs. It performs the following activities:

1. Activate the SETUP module that is used to specify the DOS path, the project's file name and the units to be used.

2. Display the main menu with help highlights of each of the program functions.

3. Allows shelling to the program that is selected.

Each of these above mentioned program can be run independently provided the required data for the program has been exists.

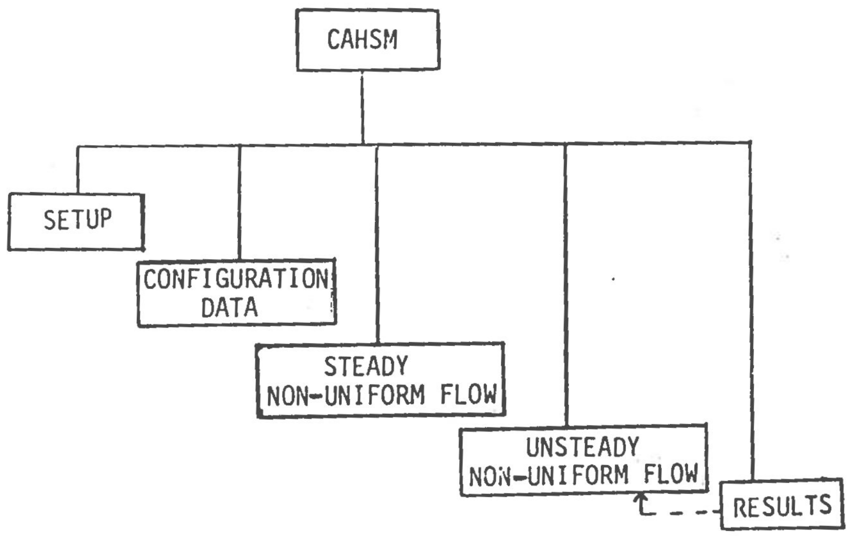


Figure 9. Flowchart depicting CAHSM's principle options and their relationship under the menu system.

SETUP

The setup option is used to create, view or modify RUNFILE, a data file that is used by all programs and to specify the data files to be used and the units of measurements.

When this option is selected, the program reads RUNFILE and displays the default DOS path, project's filename and units of measurements to be used and allows the user to change any of them.

DOS path specification

Make sure that you enter a valid DOS path, otherwise runtime error will occur as the program tries to open a file in a non-existing directory.

Project's filename

All the data for a particular simulation bear the same name with different extensions. Any valid DOS file name is acceptable and should consist of at most 8 characters with no blanks in between characters.

Units of measurement

This program allows the user to specify the units of measurement, English or Metric units. The kernel programs, CANGVF.EXE and CANOPER.EXE perform the computations in metric units but display the input and output in the user selected option.

Utility Program

CANUTIL.EXE is the utility program that is used for solving for any one unknown in the Manning's and control structure equation. Input and output may be in either English or Metric units. Run SETUP to select the appropriate units before calling this program.

Governing Equations

Manning's equation (Eq. 8)

Critical depth

$$\frac{Q^2 T}{g A^3} = 1.0 \tag{10}$$

Control structure equations

Overflow structure $$Q = C_d W (Y - h_s)^{3/2} \tag{11}$$

Rating formular $$Q = m\,(Y - h_s)^n \tag{12}$$

Underflow structure $$Q = C_d A\,[2g\;\;H]^{1/2} \tag{13}$$

Data Requirement

The required data depends on the unknown variable. Only one unknown can be solved for each time. Therefore, to obtain the correct solution ensure that all the other variables are correctly defined.

Computational Procedure

Manning's Equation: Solving for Q, n, and S_0 is achieved by rearranging the equation. However, the solution for the cross section variable (b, y, and z) involves the use of Newton Secant method. For example, solving for y requires rearrangement of the equation as shown below. The solution is obtained when F(y) = 0.

$$F(y) = \frac{c\,[by + zy^2]^{5/3}}{n\,[b + 2y(z^2 + 1)]^{2/3}}\, S^{1/2} - Q \qquad (14)$$

Solution for b, and z can be obtained in a similar manner.

<u>Critical flow condition</u>: The critical flow conditions occur when the froude number is equal to unity:

$$\frac{Q^2 T}{g A^3} = 1 \qquad (15)$$

This equation can be rearrange and rewritten as:

$$F(y_c) = Q^2(b + 2my_c) - g(by_c + my_c^2)^3 \qquad (16)$$

The critical depth y_c is obtained by applying the Newton Secant technique to the above equation. Critical slope is obtained by solving the Manning's equation for s_0 when $y = y_c$.

<u>Control structure equations</u>: Solution for flow variable in overflow and stage discharge rating formula and underflow structure under submerged flow conditions is obtained by rearranging the equation. The challenge lies in solving for the gate opening (G_0) under submerged flow conditions (Eq. 17).

$$Q = C_d W G_0 [2g(y - (h_s + G_0/2))]^{1/2} \qquad (17)$$

The gate opening is evaluated by rearranging the equation and applying Newton-Secant method.

Application

Solving for flow depth: A trapezoidal channel is 7.9 m wide, side slope 1:1 and is cut in rock for which the roughness coefficient is assumed to be 0.02. If the design discharge is 22 m^3/s and the longitudinal slope is 0.0006, compute the normal depth and compare it with critical depth.

Assuming that you are in the directory where CAHSM and related programs are proceed as follows:

1. Type CAHSM and press enter;
2. Select SETUP option and make sure that the units are metric. The DOS path and filename are not required by this program because no output data files are created;
3. Select UTILITY option and enter the flow variables; and
4. Press F9 key to calculate.

The answer is
Normal flow depth = 1.62 m
Critical depth = 0.89 m

Sub critical flow conditions exists.

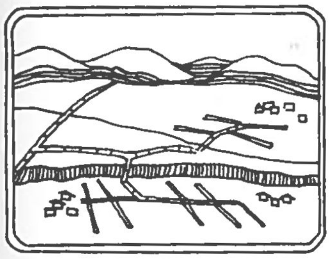
Control structure setting: Determine the width of a weir required to pass the discharge in the above case ($Q = 22\ m^3/s$) at normal flow, a sill height (h_s) of 0.3 m and a discharge coefficient of 1.86

1. Select the control structure window;
2. Enter the control structure variables; and
3. Press F9 to calculate

The answer is W = 7.8 m

Configuration Data

The importance of correct data in computer simulation cannot be overemphasised because the program simply transforms the input into an output by analzing the hydraulic relationships and consequences, the accuracy of a simulation depends on the quality of input data. This section describes the computer program's configuration data requirements and illustrates how to create, view and/or modify data.



The configuration data describe the physical facilities of the canal network to be studied. The canal network is divided into branches and reaches for the purposes of simulation. The uppermost branch becomes Branch 1 and others are numbered consecutively to the most downstream branch. The branches are divided into reaches. The end of a reach is determined by the presence of a cross-canal structure, any change in canal cross-section, slope or roughness, or any other structure that affects the canal water surface elevation on the upstream side.

Configuration Data Requirement

Configuration data required for hydraulic modeling of a canal network can be obtained from design drawings and/or field surveys and calibrations. These data are collected during the initial installation of the model and should be updated to reflect any changes in the physical system that will significantly affect the hydraulic relationships. For example:

1. Deterioration in canal lining and/or proliferation of aquatic weeds increases the flow resistance and re-evaluation of Manning's roughness is essential.

2. Rehabilitation of flow control structures requires an evaluation of the new discharge coefficient.

Configuration data is sub-divided into the following groups for convinience:

1. Hydraulic and hydrologic linkages;
2. Channel cross section and longitudinal data;
3. In-line control structures; and
4. Turnout control structure.

Hydraulic and hydrologic linkage

Open-channel water conveyance and distribution systems consist of conveyance canals that extend from the water source to the various outlets that supply water to a group of users (see Fig. 1). In modeling such a network, it is necessary to break it up into hydraulic units separated by control structure. Each unit is linked hydraulically to the one upstream and downstream (if submerged flow conditions exist) and hydrologically to the one upstream. These units are called reaches. A series of reaches that are hydrologically linked to the reach upstream by flow through the in-line control structure form a branch. The uppermost branch is hydrologically linked to the network headworks, whereas the others are linked to the branch, reach, and turnout that feed them.

Figure 10 illustrates how the canal network in Fig. 1 is sub-divided. Table 2 shows the hydrologic linkages of all the branches. Branch 0, reach 0, and turnout 0 represent the network water source.

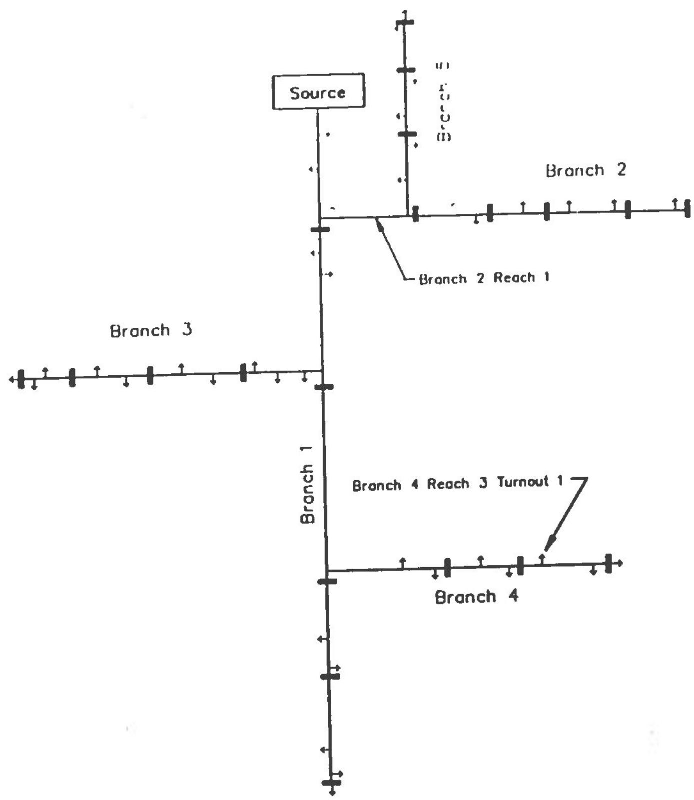


Figure 10. Schematic Representation of a Branching Canal Network

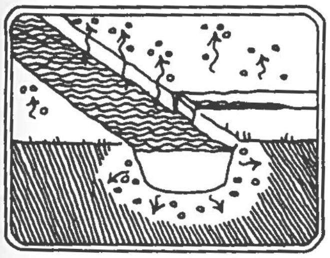
Table 2. Branch Hydrologic Linkage

	Branch Inflow Source		
Branch	Branch	Reach	Turnout
1	0	0	0
2	1	1	3
3	1	2	3
4	1	3	1
5	2	1	2

Channel cross section and longitudinal data

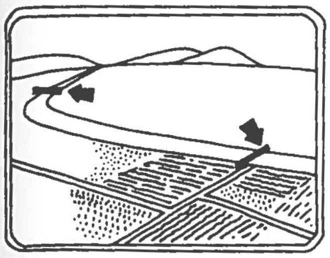
Cross-sectional data. The model assumes that the canal is prismatic. The cross sectional data required includes the maximum flow depth (Ymax) in m. (ft), design or normal flow depth (Yn) in m. (ft), bottom width (B) in m. (ft), and side slope (z). If the design drawings are not available these data can be obtained by field measurements. If there is a lined canal, the cross-sectional data are readily obtained. For irregular cross-sections, it is necessary to obtain an equivalent bottom width and side slope that results in an equivalent depth-area relationship.

Longitudinal data. The longitudinal data describe the reach longitudinal profile. The pertinent data in this category include: (1) channel losses in cm/day (inches/day), (2) longitudinal slope in m/1000m (ft/1000ft), (3) the channel roughness coefficient, (4) length of the reach in m. (ft), and (5) the characteristics of the transition between reaches.



Conveyance Losses

Channel losses are a function of channel properties and flow rates. These in turn depend on (1) size of the command areas; (2) cropping patterns; (3) irrigation methods; and (4) the season of the year. Channel losses include seepage, leaks, evaporation, and canal bank vegetation transpiration losses as well as any undetected unauthorized use of water. Channel losses are the most difficult variables to evaluate with reasonable accuracy due to the high spatial variability in seepage. The methods are available for evaluating channel losses include: (a) inflow-outflow; (b) ponding; and (c) seepage meter measurement. The model user is encouraged to obtain more details on this subject in order to more effectively evaluate the channel losses. The model input is expressed in cm/day (inches/day). Where data are available in the form of conveyance efficiency, loss in m^3/s (cfs), etc., attempts should be made to convert it to cm/day



Inflow-Outflow Method

(inches/day) over the wetted perimeter. If there is significant evaporation and leaking structure loss, these values should be evaluated and incorporated in the channel loss equation.

Longitudinal slope obtained from design data should not be relied on completely due to construction deficiencies in meeting design specifications and to channel bottom deterioration as a result of scouring and silting. An average slope value should be obtained by profile surveying at several locations along the reach.

The roughness coefficient is an indicator of the channel resistance to flow. This is one of the most elusive model parameters due to its variability in space and time. The roughness coefficient is influenced by many factors, some of which are listed below:

1. Surface roughness;
2. Channel vegetative cover;
3. Channel irregulaties;
4. Silting and scouring; and
5. Stage and discharge.

The program uses one value for the roughness coefficient per reach. The value selected should represent the average conditions in the reach so as to establish the discharge-area relationship accurately. Thus, the Manning's n is the parameter of interest. Most hydraulic text books present a guide to proper selection of Manning's n and a summary has been included in the on-line help system in the model.

The transition between reaches is delineated by the structure (eg. siphon, drop chute, etc.) that separates the reaches. Two parameters that describe the transition are required: (1) distance between the control structure and beginning of next reach (especially in case of an inverted siphon or drop); and (2) the change in canal invert elevation.

Control and turnout structures

The control and turnout data (sill height, structure width, maximum gate opening) can be obtained by taking direct measurement of the structure or from design drawings.

Overflow structure: The discharge through an overflow structure is obtained using a simplified form of Eq. 3 as shown below.

$$Q = C_d W h_u^{1.5} \qquad (18)$$

In the above equation the user is requested to enter the values of C_d (approximately 3.3 in english units and 1.86 in SI units); W, and h_s in the appropriate units. For adjustable overflow structures the value h_s represents the minimum value of the sill height and the actual operation of the structure is specified as operation data.

Underflow structure: In this case the user specifies the C_d, W, and maximum gate opening (note W = diameter for a circular orifice) and the program calculates the discharge based on the flow conditions. The program use the previous time steps downstream flow depth to evaluate the operating head. The gate opening b, is specified as part of the operational data.

Number of structures: Sometime the flow is regulated by more than one identical structures, such as a number of sluice gates or pumping units. The model allows the use of multiple structures but all have to be of the same size and stage-discharge relationship. The structure geometry and stage-discharge relationship is required for only one unit. The total discharge is obtained by multiplying the discharge of a single unit by the number of units (N_s).

For example, assume tha you have three pump units with the following discharge capacities, 0.5, 1.0, and 2.0 m^3/s. The control structure has a total discharge of 3.5 m^3/s. The pump units are switched off when the flow depth drops below one meter.

This data can be entered as follows:

1. Structure type 3
2. Sill height 1.0 m
3. Number of pump units 7.
4. Discharge coefficient 0.5
5. Discharge exponent 0.0

To simulate a case in which the discharge is 2.5 m^3/s, the number of pump units operating (N_s = 2.5/0.5 = 5).

<u>Location of structures</u>: Location of inline control structures depends on the canal slope, the flow control concept used, number and size of turnouts along the canal reach, and the desired flexibility in operating the system. These control structures are normally located where they provide the following:

1. Sufficient head on all the turnouts even during low flow conditions; and

2. Minimize water level fluctuations that result from inflow and/or outflow rate changes.

The program considers the location of the in-line control structure to be the end of the reach.

The location of secondary canal off-takes and farm turnouts is affected by the topography, command area location, canal network layout, and the water control method used. The program allow for the location of the turnout control structure any where within the reach so long as no two structures overlap.

Running CANDATA Program

Before starting to run the data entry program make sure that you have all the required data. This will prevent you from guessing some of the values which may lead to numerical inconsistency or simply erroneous results. When simulating a hypothetical system, run the UTILITY program to give you some ideas of the hydraulic relationship of the model input data.

To enter configuration data for the canal system shown on Fig. 1, the canal network is divided into branches and reaches as shown on Fig. 10. The following discussion illustrates the step by step procedure in data entry.

The program, CANDATA.EXE is used for initial entry, editing or simply display of the system configuration data. This program can be run individually or within CAHSM environment. The data is store in the file specified by the RUNFILE that currently exist in the default directory.

The user is guided through menu-driven commands in the selection of data entry options. For a first time entry of system data, the user is required to identify the size of the project to be simulated in terms of the number of branches and number of reaches in each branch. It is recommended that the user start with a one branch-one reach unit and build it up unit wise, saving the data after completion of each additional reach data entry.

Assuming that the CAHSM and related programs reside in the default directory proceed as follows:

1. Type CAHSM and press enter
2. Select SETUP option and enter the DOS path, project's file name, and units of measurements.
3. Select CONFIGURATION DATA option.
4. If there is no data file by the name you specified, the program request you to confirm that you will be entering a new set of data.
5. Even though the canal network has five reaches, start by entering data for one branch with two reaches. You can build on it later.
6. Enter the data for each screen page and press PgDn key to move to the next screen.
7. Proceed until all the data is entered. The end of the data is depicted by a return to the configuration data entry menu.
8. Save the data. This is accomplished by selecting option B in the configuration data menu.
9. Select option C to terminate configuration data entry. The data you have entered can be retrieved at any time and modified as need be.

The data are stored in a filename that was specified in the SETUP menu and bears the extension .CFG. The structure of the data file is outlined below.

Number of branches

Branch information (Repeats for each branch in the project)

- Branch that supplies water to this branch
- Reach that supplies water to this branch
- Turnout that supplies water to this branch
- Number of reaches in this branch

Reach information (Repeats for each reach in the branch)

- Number of turnouts
- Maximum canal depth
- Design flow depth
- Side slope
- Bottom width
- Seepage rate
- Manning's n
- Longitudinal slope
- Length of the reach
- Distance between reaches
- Change in canal invert elevation between reaches

Reach water control structure information

- Type
- Sill height
- Discharge coefficient
- Gate opening
- Width of structure

Reach turnout information (Repeat for each turnout in the reach)

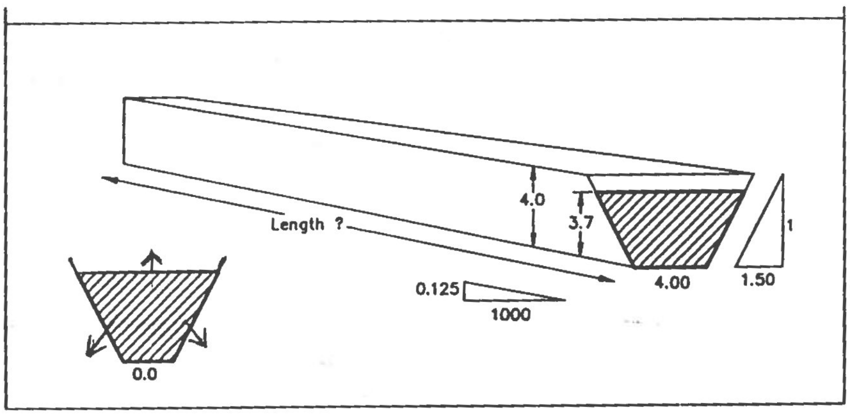
- Type
- Sill height
- Discharge coefficient
- Gate opening
- Width of structure
- Location (distance from upstream end of the reach)

TABLE 3. Tabular Data Display and Editing Screen.

REACH INFORMATION

BRANCH 1 REACH 1

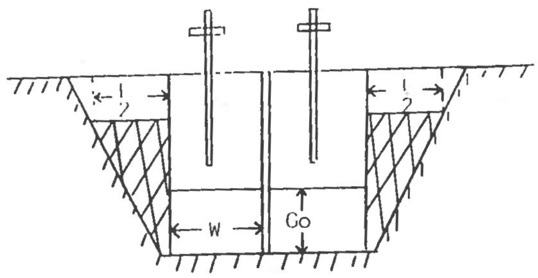
CROSSECTIONAL DATA	
Max Flow Depth in meters	4.00
Normal Flow Depth in meters	3.70
Side Slope	1.50
Bottom Width in meters	4.00
LONGITUDINAL DATA	
Channel losses in cm/day	0.00
Manning's N	0.014
Longitudinal slope in m/1000m	0.125
Length of the Reach	10000.00
Length of Structure between reaches .	0.00
Change in canal bottom elevation	0.00

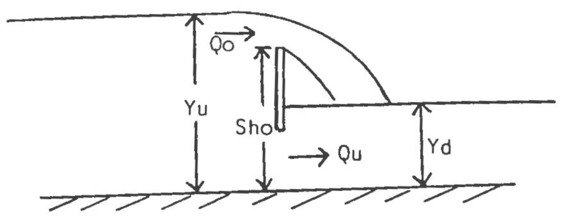


CONTROL STRUCTURE

BRANCH 1 REACH 1

TYPE (Rectangular Gates)	5
Number of Structures	2
Minimum sill height	0.0
Discharge coefficient	0.61
Width of the structure	2.00
Maximum Gate Opening	2.40
Overflow structure	
Minimum sill height	0.4
Discharge coefficient	2.40
Width of the structure	4.00





$$Qo = CdL(Yu - Sho)^{3/2}$$

$$Qu = CdNsGoW[2g(Yu - Yd)]^{1/2}$$

$$Q = Qu + Qd$$

Steady Non-uniform Flow

Irrigation canals are usually designed for full supply conditions. Under these conditions, the flow is nearly uniform and appropriate deliveries can be made. However, if the demand is reduced and canals are left unchecked, water levels would fall below required limits for deliveries. To avoid such occurrences, irrigation canals are provided with control structures. During the low flow period, these structures serve to raise the water level allowing appropriate deliveries to be made. This creates non-uniform flow conditions which depend on the control structures location, size and their operation. The resulting water surface elevation are of importance in the design and operation of a canal network.

The program is intended for calculating water surface profile for steady gradually varied flow in man-made channel of trapezoidal cross section. Inputs and output can be in either English or Metric units.

Theoretical Basis and Computation Procedure

Only subcritical flow profile in a mild slope is considered. The computational procedure is based on the solution of the one-dimensional energy equation (Eq. 9). Energy loss is evaluated using the Manning's equation.

In solving for gradually varied flow profile (M1 and M2) the solution begins at the downstream end where Q and y_0 are known and continues to the upstream end of the reach. The method used to solve the ordinary differential equation is divided into two steps: (1) starting the solution, and (2) continuing the solution (Flammer, Jeppson and Keedy, 1982).

Data Requirement

The data required for computing the steady state flow profile consist of configuration data and initial flow conditions data. The initial condition data specified the flow deliveries at all the demand nodes and the flow depth at the downstream end of each reach. These data are stored in a file with an extension .INT.

Program output

This program computes the flow depth along the canal and the control structure setting required to supply the specified deliveries. The program also generates the initial conditions data for the operation study. These data are stored in a file with an extension .STS.

It is sometimes necessary to start the simulation with a predetermined steady state condition. The CANGVF program is used to compute the initial steady state flow conditions for the specified physical configuration and the initial depths and flow rates. This is a stand alone program but requires that configuration data with the name in the RUNFILE be available.

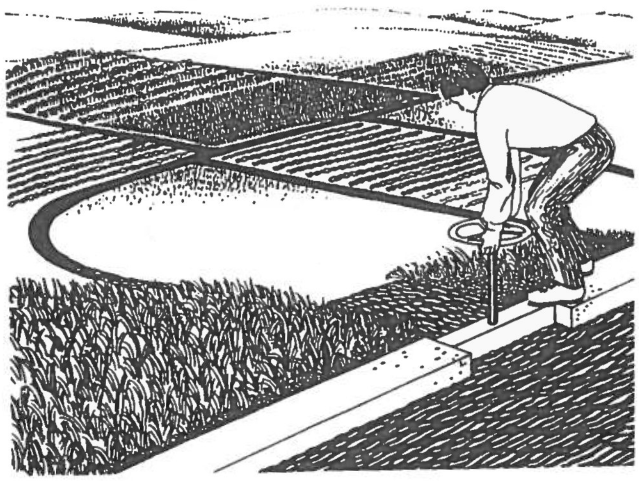
Uses of the program

1. Evaluate the steady state water surface profile;
2. Determine the steady state control structure setting;
3. Calibration of flow parameters (roughness coefficient, discharge coefficient, and longitudinal slope); and
4. Compute a steady state initial condition for unsteady nonuniform flow simulation.

Unsteady Non-uniform Flow (Operation Study)

Operators of manually controlled canals and laterals often find it difficult to maintain stable water surface profiles while making necessary operation of regulating structures. This is caused by the complex interplay between structures in series that may cause hydraulic transients to build up and create undesirable conditions. Optimal operation can be achieved only from proper operation of the entire network. Use of the model will not only eliminate these incompatibilities, thereby minimizing problems associated with nonuniform unsteady flow deliveries, but will also permit the adequate and reliable deliveries to be made.

The operation study is used to study the effect of various operations on the canal hydraulics. It simulates steady or unsteady, uniform or nonuniform flow regimes. Each run simulated 12 hours of canal operation. It is based on solving Equations 1 and 2. The solution of these equations can be used to predict hydraulic responses of the canal network changes in headworks inflow and control structure operations.



Initial Conditions

The model has two initial conditions options, empty canal, previously computed hydraulic status.

Empty canal filling: When water is introduced into a dry canal, the advancing front analysis is equivalent to the advance phase of furrow irrigation although occurring more rapidly because of higher flow rate, less resistance and seepage loss. Simulation of this phase is, therefore, similar to that presented by Walker and Skogerboe (1987).

Previously computed hydraulic status: This option also allows the program to start simulation at a status specified by the user. This could be the profile computed by the steady state study outlined above or the profile save at the end of a 12-hour simulation. The model saves the hydraulic status at the end of each simulation run which becomes the initial condition for the next simulation period. It is stored in a file with an extension ".STS." Below is an outline of the suspended simulation status data file structure.

Number of branches

Branch information (Repeats for each branch in the project)
- Branch that supplies water to this branch
- Reach that supplies water to this branch
- Turnout that supplies water to this branch
- Number of reaches in this branch

Reach information (Repeats for each reach in the branch)
- Number of turnouts
- Maximum canal depth
- Design flow depth

Side slope
Bottom width
Seepage rate
Manning's n
Longitudinal slope
Length of the reach
Distance between reaches
Change in canal invert elevation between reaches

Reach water control structure information

Type
Sill height
Discharge coefficient
Gate opening
Width of structure

Reach simulation status information

Left node number
Right node number
Number of turnouts incorporated into the solution
Operation mode control status
Control structure setting
Reach inflow
Reach outflow

Reach turnout information (Repeat for each turnout in the reach)

Type
Sill height
Discharge coefficient
Gate opening
Width of structure
Location (distance from upstream end of the reach)

Reach simulation status information

Computational node to the right of this

turnout
Turnout discharge
Turnout setting

Flow profile information
Flow cross-sectional area
Discharge rate
Distance of node from upstream end of the reach
Length of the computational node

<u>Operational Data Requirement</u>

The operational input represents the dynamic inputs of the system which include and depend on the mode of operation. These data are stored in a file with the following extensions:

project.RFR - Contains system inflow hydrograph

project.CSS - Control structures setting data

project.TSS - Turnout structure setting data

project.DMD - Demand hydrograph at all the demand nodes

The operational data required depends on the mode of operation as will be discussed below.

<u>Operator specified control</u>: Operator specified control is a option used to simulate the system under full manual control of an operator. All decisions on the flow rates and control structure settings are made by the model user. The input data are therefore:

1. An inflow hydrograph into the system; and
2. Regulating structure settings for all in-line and turnout structures for the entire simulation period.

Upstream depth control: Upstream depth control options allow the computer to simulate the regulating structure settings required to maintain a predetermined flow depth upstream of the structure and at the same time meet the demands below and from turnouts. The input data are the demand hydrographs for all turnouts in the system.

Downstream discharge control: Downstream discharge control option allows the computer to determine the flow rate and control structure settings required to satisfy a given demand to the lower reaches. The input data are the same as above.

Program Output

Output Displays: Computers normally generate output at a faster rate than a human mind can assimilate. Therefore, when output is to be displayed on the computer screen, it should be presented in a manner that optimizes the communication between the user and the computer. In this program, the output is arranged in the most logical sequence so that information needed for understanding any point is provided in advance insofar as possible. Scrolling screen output is avoided because it differs from the natural reading technique in that the material moves upwards instead of the eye moving downward across a steady display. Tabular data are displayed in logically related groups which fill the screen.

The model output consists of flow depths, flow rates and structure settings for in-line or turnout structures. This information is displayed on a graphical screen as shown on Fig. 11. The top window displays the flow profile of all of the reaches in the branch. This plot is updated at the end of each time step. The middle left window displays branch inflow and reach outflows while the lower one displays in-line structure settings. The middle right window displays turnout discharges while the lower one displays the turnout settings. These displays provides past and current values of the flows and structure settings.

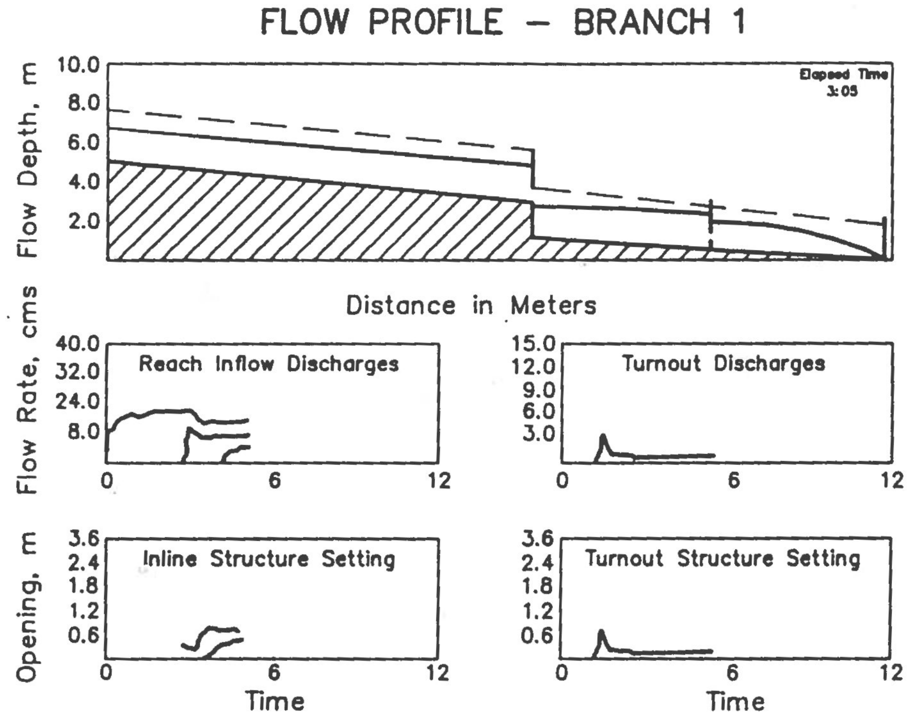


Figure 11. Graphical Output Display Screen.

The second option of output display is tabular. The tabular output consists of a fill-out form display in which only the numeric data are updated on a stable screen. Only one branch output can be displayed at a time. Thus, when simulating a system with more than one branch, the user selects the branch of interest and toggles to it from the current branch by simply keying in the number corresponding to the branch. The program redraws the background and past simulation status for the branch before proceeding on to display the current status.

User Interrupt: When running the program in an interactive mode, the user's interest in monitoring the simulation and intermediate output becomes exceedingly important and simulation interrupt capabilities vital. In simulating the effects of alternative future actions in a changing environment, the displays of both current and past results are crucial. This enables the user to observe the results, stop to critically examine any phase of the simulation, modify future actions, or go back in time and change model parameters, and then continue the simulation.

At the beginning of each time step loop, the program scans the keyboard buffer to determine whether any key had been pressed and reacts accordingly. The following interrupt options are provided:

1. **F1 key** - The program temporarily halts simulation and pulls out the on-line help menu;
2. **F2** - Toggles the runtime output between existing branches;
3. **F4** - Toggles the runtime turnout graphical output between existing reaches;
4. **F6 key** - The program pauses simulation, giving the user time to critically examine the output display;
5. **F8 key** - The program switches from graphical output display to tabular form and vice-versa;
6. **F10 key** - view and/or modify operation data;
7. **Esc key** - The program aborts simulation.

Simulation Result

At the end of each 12-hour simulation, CANTRAN.EXE program output is stored in data files for later viewing or printing. The CANRES.EXE program manages the display and printing of these output. The output is subdivided into nine categories:

1. Headworks inflow;
2. Reach outflow;
3. In-line structure settings;
4. Turnout structure settings;
5. Turnout demand hydrograph;
6. Turnout supply hydrograph;
7. End of branch demand hydrograph;
8. Upstream flow depth; and
9. Downstream flow depth.

Error Messages

1. <u>File not found</u>: The program has failed to access the file in the directory specified by the current DOS path.

2. <u>Convergence failure</u>: The solution to the governing equations has failed. This is caused by rapid changes in the flow control parameters such as:
   a. Opening or closing the control structure too rapidly; and
   b. Rapid change in inflow

APPLICATION OF THE MODEL

The general consensus is that irrigation performance is constrained by our ability to make the right decisions and that the provision of the necessary tools and methodologies will go a long way in improving the performance. Walker and Skogerboe (1986) observed that:

> Analysis of an irrigation system must be prepared to deal with a multitude of important linkages between the watershed, storage facilities (if present), main system and the individual command areas. These linkages are not generally considered in sufficient details during the design, operational or rehabilitation phases of an irrigation project. As a consequence, a large variety of operational weakness have developed.

In searching for system improvements, there is a need to predict the system's behavior for various operating scenarios and to determine the appropriate procedure to achieve the desired objective. The advent of computers and the development of numerical and systems analysis technology is luring researchers and facilitating the development of multi-disciplinary methodologies. Advances in computer technology have resulted in the introduction of rugged, affordable micro-computers with ample computing power and memory.

The increased availability of this cost-effective technology has stimulated the development of improved analytical tools and methodologies for evaluating alternatives so that the best possible decision can be made. This is making the synthesis and analysis of alternative future designs and operational policies more readily available to engineers, planners, and system operators throughout the world.

It is, however, important to stress the fact that: (1) the micro-computers will only produce technically feasible solutions, and therefore, financial, socio-economic, and political acceptance of these solutions should be reviewed before arriving at the final operating procedure; and (2) the use of models should be complementary to the study of the real system and therefore any model solution must be ultimately proven in a real system setting.

Uses of the Model

The CAHSM model provides irrigation professionals and amateurs with a vehicle to address issues related to the interaction between design and operation of a canal network as one pursues a more dynamic operation and management of the conveyance network. It can be used to: (1) evaluate the hydraulic response of the conveyance network to changes in physical and operational features of the system to determine the best combination of controllable parameters to achieve pre-decided system performance goals; (2) establish opportunities and constraints of the system; (3) determine points in the system that are sensitive to managerial interference; (4) predict system behavior; and (5) provide guidelines on possible improvements on water control over the entire system. Some of the specific uses of the model can be grouped into three categories: (1) design issues; (2) evaluation of required interventions; and (3) operational and training issues.

Design issues include:

1. Investigating the effect of different control structures on canal hydraulics;

2. Determining the optimal type, number, and location of control structures;

3. Investigating the need for intermediate reservoirs, their location, and their capacity in order to reduce the spills and reduce system lag time; and

4. Subjecting the conveyance and distribution system design to various operating scenarios to identify operational bottlenecks before the system is constructed.

Evaluation of possible interventions include:

1. Determining the hydraulic response (lag time, water level and discharge fluctuations) associated with varying levels of maintenance;

2. Determining operational schedules and policies that are most appropriate for good management; and

3. Evaluating the performance of an existing system to determine the need for rehabilitation.

Finally, operational and training issues include:

1. Determining the optimal control structure settings required to minimize the discrepancies between demand and supply;

2. Determining the optimal inflow hydrographs for a given command area's demands;

3. Determining the effects of the command area's rejected demand on the canal hydraulics and the appropriate control structure settings to minimize the spills;

4. Determining the optimal filling and emptying time of the channels in order to: (a) minimize losses; (b) minimize delayed deliveries; and (c) prevent rapid filling or draining of the channels;

5. Determining the optimal hydrograph and control structure settings that will minimize water level fluctuations and/or limit rapid filling or drawdawn; and

6. Training operational staff on how best to operate and manage the system.

Use of CAHSM in Real Time Management

The conveyance system is a complex setup that is influenced by the natural (physical and biological) and human factors. Before embarking on the use of the model in the improvement of the system performance. The following questions should be addressed:

1. What are the existing procedures, and could better results be achieved by using other procedures which are more appropriate to the local needs?

2. What procedures are socially, economically, financially, and technically feasible? and

3. What resistance to changes should we expect?

The CAHSM model can be used for real time management of irrigation canal networks that experience frequent canal transients. The benefits of using the model stem from the models capability to:

1. Process the overall data and generate a comprehensive control schedule;

2. Incorporate farmers' demands making it possible to deliver water on demand without excessive seepage and operational losses;

3. Use stored past simulation or generate a steady state start-up condition and compute flow propagation in order to detect possible disturbances, rapidly and accurately, and devise strategies to alleviate the disturbances; and

4. Generate water control strategies for specific contexts, such as: (a) the beginning and end of season, (b) shortage periods, (c) reach closure, (d) and control structure failure, etc.

To take full advantage of the model's capabilities, the working environment must be conducive to sustained computerized irrigation management. Control of this dynamic system requires:

1. Physical structures that facilitate conveyance, flow measurement, and that are easy to operate;

2. Data acquisition systems that collect accurate and timely data on the system's operation and users' demands (ditch riders, extensions agents, etc.);

3. Data processing systems, consisting of engineers, computers, and calculators, that will quickly and accurately analyze incoming data and issue appropriate operating instructions;

4. A system to implement the operating instructions accurately and without bias (ditch riders); and

5. A fast and accurate communication link between the data acquisition, data

processing, and the execution of the operating instructions.

Specific items of concern to the viability of computerized conveyance system management are:

1. Will the hardware and software work reliably in the environment;

2. What contingency plans should be made in case of hardware failure;

3. Will there be qualified computer operators and programmers available to make modifications to suit the changing physical and operating settings;

4. Is sufficient and accurate data available, and if not, could missing data be obtained at a reasonable cost;

5. Can a reliable communication between model operators and field personnel be established and sustained; and

6. Would the results of the model be used regularly or would model application be abandoned in favor of the old and easy operation and management routine?

In applying the model, the following activities are proposed:

1. Periodic and careful re-calibration of the model to take care of any changes in the physical system;

2. Collection of adequate and accurate data;

3. Daily simulation to develop water delivery procedures and plans that reflect current water users' demand and climatic conditions;

4. Comparison of the planned system operation with actual system operation so that appropriate initial conditions are used at the beginning of each simulation period; and

5. Monitoring deviations between simulated and actual performance so that the necessary improvements in model calibration and/or system operation can be identified and corrected.

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WATER MANAGEMENT SYNTHESIS PROJECT REPORTS

WMS 1 Irrigation Projects Document Review

Executive Summary
Appendix A: The Indian Subcontinent
Appendix B: East Asia
Appendix C: Near East and Africa
Appendix D: Central and South America

WMS 2 Nepal/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 3 Bangladesh/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 4 Pakistan/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 5 Thailand/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 6 India/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 7 General Asian Overview

WMS 8 Command Area Development Authorities for Improved Water Management

WMS 9 Senegal/USAID: Project Review for Bakel Small Irrigated Perimeters Project No. 685-0208

WMS 10 Sri Lanka/USAID: Evaluation Review of the Water Management Project No. 383-0057

WMS 11 Sri Lanka/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 12 Ecuador/USAID: Irrigation Sector Review

WMS 13 Maintenance Plan for the Lam Nam Oon Irrigation System in Northeast Thailand

WMS 14 Peru/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 15 Diagnostic Analysis of Five Deep Tubewell Irrigation Systems in Joydebpur, Bangladesh

WMS 16 System H of the Mahaweli Development Project, Sri Lanka: 1980 Diagnostic Analysis

WMS 17 Diagnostic Analysis of Farm Irrigation Systems on the Gambhiri Irrigation Project, Rajasthan, India: Volumes I-V

WMS 18 Diagnostic Analysis of Farm Irrigation in the Mahi-Kadana Irrigation Project, Gujarat, India

WMS 19 The Rajangana Irrigation Scheme, Sri Lanka: 1982 Diagnostic Analysis

WMS 20 System H of the Mahaweli Development Project, Sri Lanka: 1983 Diagnostic Analysis

WMS 21 Haiti/USAID: Evaluation of the Irrigation Component of the Integrated Agricultural Development Project No. 521-0078

WMS 22 Synthesis of Lessons Learned for Rapid Appraisal of Irrigation Strategies

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