MATHEMATICAL MODELING OF THE KALANKUTTIYA BRANCH CANAL

APPLICATION OF SOFTWARE "MISTRAL/SIMUTRA"

Hilmy Sally

INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE
Digana Village, via Kandy
SRI LANKA

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I INTRODUCTION

The study of the interactions between the <u>design</u> and <u>management</u> of irrigation systems in a given environment constitutes one of the major themes around which IIMI articulates its research programs.

In many of the large irrigation systems of Asia, design and management of main systems are important because performance achieved at this level could have far-reaching impact on the subsequent distribution of water. Efficient management of water conveyance over long distances in main canals and into distributory canals suffers due to the lack of, or ineffective, control facilities provided for in the design of the system. This often results in an inflexible and unreliable water supply regime which could negate many of the efforts to improve management below turnouts.

These assumptions provide a rationale for IIMI's two-pronged approach to carrying out research under this theme:

(1) To evaluate the impact of current design on the manageability and performance of main canals in Asia, commencing with Sri Lanka, and

(2) To assess the prospects for improving system performance through innovative design and management practices.

IIMI will address the first of these issues in Sri Lanka by undertaking a comparative study of at least three systems exhibiting substantial differences in the design of their main canals: Kalankuttiya Branch of Mahaweli System H (duck-bill weirs); Kirindi Oya (gated cross-regulators), and Rajangana/Huruluwewa (automatic hydro-mechanical level control).

IIMI will employ mathematical models for flow simulation in main irrigation canals as research tools for addressing the second issue. However IIMI does not seek to develop these models itself since it recognizes that a number of such models (usually based on algorithms for the resolution of the laws governing the hydraulics of open channels) have already been developed and are being used by universities, research organizations and consulting firms. IIMI's aim is therefore to adapt and apply this available body of knowledge to the fulfillment of its own mandates in research as well as in training. IIMI may, from time to time, call upon the services of external resource persons to help it in this respect.

It was in this spirit that IIMI recently contracted with the French consulting firm, SOGREAH, to furnish us with their micro-computer software package for flow simulation in canals "MISTRAL/SIMUTRA".

The objective of this paper is to describe the software, its data requirements, output, and potential use through a discussion of its application to the Kalankuttiya branch canal within the Mahaweli System H in the North-Central Province of Sri Lanka.

II DESCRIPTION OF KALANKUTTIYA BRANCH CANAL

The Kalankuttiya sub-system is located within System H of the main Mahaweli system, in the North-Central Province (NCP) of Sri Lanka. The 1.86×10^6 m^3 Kalankuttiya tank at the head of this sub-system commands an irrigable area of 2040 ha. The tank's own catchment area is only 26 km^2 but its water resources are being supplemented, since 1977, by Mahaweli water diverted to the larger Kalawewa reservoir.

The conveyance and distribution system is made up of a 11.5 km long branch canal having a maximum design capacity of 5.66 m^3/s (200 cusecs) conveying water from the Kalankuttiya tank to 20 distributory canals, which in turn feed a network of field canals. Each field canal irrigates between 6 and 25 farm allotments of 1 ha size through a 15 cm (6 in) pipe outlet. The number of farms served by a field canal varies due to the undulating nature of the land and the wide range in sizes of the micro-catchment land units in this topography.

Nine duck-bill weirs constructed along the branch canal help maintain hydraulic head at distributory canal offtakes irrespective of fluctuations of discharge in the branch canal. Control of discharges into a majority of the distributory canals is thereby enhanced.

III SOFTWARE DESCRIPTION

The simulation software consists of two distinct modules :

- the numerical flow resolution module called "MISTRAL", and
- the graphic output module called "SIMUTRA".

MISTRAL itself acts in two phases, a model coding phase and a calculation phase. In the first phase coded instructions are prepared on the basis of the data contained in the model configuration file. These instructions are made use of in the second phase to generate a numerical solution of the Barre de St Venant's equations[1] by means of an implicit finite difference technique.

SIMUTRA produces graphical outputs of the computational results generated by MISTRAL.

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[1] The set of partial differential equations (Continuity equation and Dynamic equation) that describes unsteady flow in open channels

The software application could be globally represented as follows :

```
|---------------------------------------|     |--------------------------------|
| MODEL CONFIGURATION FILE              |     |          TABLES                |
| |-----------------------------|       |     | |-------------------|          |
| | Canal topography            |       |     | | Water discharges  |  O       |
| |                             |  I    |     | | Water depths      |          |
| | Hydraulic characteristics   |       |     | | Velocities        |  U       |
| | of structures               |  N    |     | | Flow volumes      |          |
| |                             |       | ___________ |-------------------|  T       |
| | Offtake gate openings &     |  P    | | MISTRAL |                        |
| | corr. hydraulic laws        |       |     |                          P     |
| |-----------------------------|  U    | ==========>     GRAPHICS          |
|                                       | ___________ |-----------------|  U       |
|     CALCULATION FILE              T   | | SIMUTRA | | Z(T)            |          |
|  |----------------------------|       |     | | Q(T)            |  T       |
|  | Initial hydraulic condns   |       |     | | Z(X)            |          |
|  |                            |       |     | | ZMAX, ZMIN      |          |
|  | Simulation time step       |       |     | |-----------------|          |
|  |                            |       |     |--------------------------------|
|  | Simulation duration        |       |
|  |----------------------------|       |
|---------------------------------------|
```

N.B.
- Z(T) : Variation of water depth with time at a given point
- Q(T) : Variation of discharge with time at a given point
- Z(X) : Water surface elevation along canal at a given instant
- ZMAX, ZMIN : Maximum and minimum water surface elevations

The source programs are written in MS-FORTRAN 77. IIMI has acquired compiled versions of these programs which are thus directly executable. The minimum hardware configuration needed for running these programs is :

- IBM-PC XT computer (or compatible) with 640K RAM and 20MB hard disk
- Monitor with Color Graphics Adaptor
- Printer (132 columns)
- Plotter compatible with HPGL language (e.g. HP 7475).

IV SOFTWARE INPUT

4.1 Canal Topology

The first step is to describe the canal to be modeled in such a manner that its physical features are represented to the required degree of accuracy. The MISTRAL/SIMUTRA programs are capable of modeling fixed structures e.g. regulating weirs, drop structures and lateral branches (inflow or outflow). The presence of other singularities where loss of hydraulic head is likely to occur, such as bridges, sudden constrictions or expansions can also be modeled. The present version of the model however cannot represent movements of gates.

The following features characterize the Kalankuttiya branch canal :

- Upstream head sluice; a head-discharge relationship, or variations of either head or discharge with time could be imposed at this point
- Conveyance channel
- Lateral offtakes (gated pipe outlets with their corresponding rating curves); are treated as upstream points by the program and should therefore be indicated as tributaries with negative discharge values
- Regulating structures, i.e. static regulators (duck-bill weirs) and drop structures, characterized by appropriate head-discharge relations
- Bridges, Constrictions and Expansions where hydraulic head losses occur
- Downstream boundary condition; the program allows only one such condition; a head-discharge relationship, or variations of either head or discharge with time could be imposed at this point

In the following discussion we shall suppose that the problem under consideration is the modeling of the first reach of the Kalankuttiya branch canal, i.e. upto the first duck-bill weir. The modeling of subsequent reaches can be performed in identical fashion.

A schematic representation of this reach is given below (not to scale).

```
        308D1                                                          308D2
          |                                                              |
          |                                       ROCKY                  |
<>=============|======|==============|=========------------==========|==========]
HEAD      |                        |            CONSTRICTION   |  BRIDGE    DUCK
SLUICE    |    GATE  BRIDGE        |       BRIDGE              |            BILL
        305D1                    305D2                       305D3          WEIR
```

Figure 1

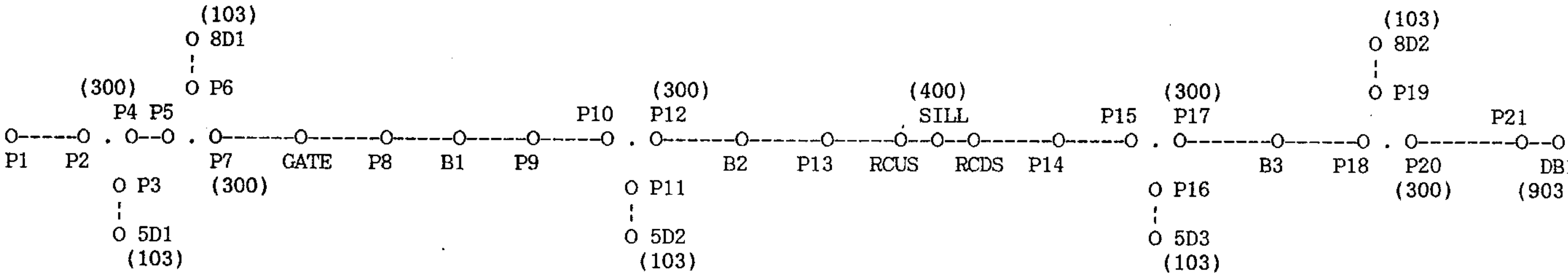


Figure 2 : TOPOLOGICAL REPRESENTATION OF FIRST REACH OF KALANKUTTIYA BRANCH CANAL

The corresponding topological (branch and node) representation of this reach of canal is indicated in figure 3.

The symbol O represents the computational points, appropriately labelled.

RCUS, SILL, RCDS are the three computational points used to account for the hydraulic head loss that may occur over a rocky constriction present over a distance of about 30 meters in the Kalankuttiya branch canal. A weir head-discharge relationship is imposed at the point bearing the code number 400 (see below). It is assumed that head loss occurs due to the abrupt expansion at the downtream end of the constriction.

Computational points (or nodes) are chosen in such a manner that the sections (or branches) bounded by pairs of nodes are reasonably homogeneous representations of the canal topography and rugosity. This choice is however constrained by the presence of (i) tributaries or offtakes since discharges into and out of the modeled canal can only occur at nodes, or (ii) any of the other topological features listed above.

Note that each offtake is represented by four computational points at the same chainage and the same elevation. For example, the offtake to the distributory canal 305D2 is represented by the points P10, 5D2, P11 and P12 in that order.

The numbers within brackets refer to the codes associated with some of the computational points that will be interpreted by the program as follows :

Code 101: Upstream boundary condition expressed in terms of a function relating discharge and time.

Code 103: Defines the upstream boundary condition in terms of a head-discharge relationship. This is the code usually used in association with the offtakes though they are in fact hydraulically downstream points with respect to the points on the main canal. All discharges entering the main canal are considered positive. In accordance with this sign convention all distributory canal offtake discharges should be given a negative sign.

Code 300: Indicates that the point bearing this code together with an associated upstream point (to be specified) form part of the same confluence. For example, in the case of distributory canal 305D2, the code 300 is used to indicate that the computational point P12 should be associated with the upstream point P10.

Code 400: Indicates that the point in question is a control section of the overflow type, e.g. sill, weir. Such a control is generally represented by three computational points at the same chainage.

Code 903: Defines the downstream boundary condition in terms of a head-discharge relationship. Two computational points are employed for this purpose. The program allows for only one downstream boundary condition. Since we are confining our discussion to the first reach of Kalankuttiya a code 903 has been imposed at the first duck-bill weir, which marks the end of this reach. If the whole length of canal is being modeled, the weir would be considered as an intermediate control section characterized by the normal head discharge relationship (Code 400).

4.2 Preparation of Input Files

(a) Model Configuration File. The model configuration file describes the state under which the system is to be studied and is created in conformity with the canal topology defined above. Among the data stored are descriptions of the canal topography (chainages, elevations, canal roughness coefficients at each computational point), turnout gate openings and corresponding rating curves, and characteristics of the regulating structures and other special points (e.g. bridges, sudden contractions or expansions in canal cross-section).

The model configuration file remains unchanged for a given series of simulations. It could however be modified if one wishes to study the canal behavior under a different state of the system, e.g. a different set of gate openings or different values of canal roughness coefficients. The user could therefore create as many of these input data files as the number of states that he is interested in studying.

In naming the input files that he might create the user should adopt the extension .DON. For example the model configuration files created for modeling the Kalankuttiya canal could be named KAMOD001.DON, KAMOD002.DON, KAMOD003.DON etc.

When MISTRAL is run with a given model configuration the program will read the corresponding input data file, e.g. KAMOD001.DON, and generate a table containing a coded description of the computational points and their conveyance factors that will be held in the computer memory for later use in the calculation phase. If the parameter IFMOD in the .DON input data file is set to 0 the coded information will not be conserved on file. If on the other hand the save option of MISTRAL is exercised (IFMOD = 2) the coded data will be conserved in a binary file under the corresponding name KAMOD001.MOD. The contents of this binary file can neither be edited nor printed. A corresponding ASCII file (named KAMOD001.RE1) is also automatically created. This file could be edited, visualized or printed via DOS utilities.

Any binary coded file (extension = .MOD) can be accessed by MISTRAL at any future time to perform simulations under different hydraulic conditions that will be defined in appropriate calculation files with IFMOD = 4 (see section (b) below).

(b) Calculation File. It is recommended that a system of nomenclature analogous to that used for the model configuration files be adopted for naming the calculation data files. Files KACAL001.DON, KACAL002.DON, KACAL003.DON etc. could thus be created.

The calculation data file contains information on the hydraulic flow regime (steady or unsteady) to be simulated, the time step and duration of the simulation, the frequency of edition and storage of the results, and the mode of initial stabilization to be adopted.

In respect of initial stabilization the user has three options, defined by the value attributed to the parameter IFSTA: (i) IFSTA = 0, impose as initial conditions the depths and discharges in computer memory, resulting from the computation immediately preceding the present one, (ii) IFSTA = 1, allow the program to perform a default stabilization procedure, or (iii) IFSTA = -1, choose as initial conditions the depths and discharges obtained at the end of a previous simulation (and contained in a file with extension =.REP; see also section 4.1), or generated by a special external procedure (GENINIT or INITALL).

The parameter IFMOD being set to 4 in a given calculation data file, e.g. in KACAL001.DON, will indicate to the MISTRAL program that the coded data pertaining to the particular model configuration on which the simulation is to be performed is contained in the file KACAL001.MOD. Before running MISTRAL with the calculation data file KACAL001.DON, the user should therefore ensure that the appropriate coded data file (KAMOD001.MOD or any other) automatically created as a result of running MISTRAL with a model configuration file (KAMOD001.DON in this case) is renamed as KACAL001.MOD. We would like to reiterate that if the desired model configuration was originally described in KAMOD001.DON the corresponding coded data would be automatically stored as KAMOD001.MOD (and not KACAL001.MOD) after the first run of MISTRAL.

The value of the parameter NBCAL in the calculation data file, e.g. KACAL001.DON, will indicate the number of hydraulic flow regimes to be simulated on a given model configuration.

V SOFTWARE OUTPUT

5.1 MISTRAL - Tabular Output

For each combination of model configuration and simulation, MISTRAL calculates the temporal variations of water depths, discharges, velocities and flow volumes at the different computational points and presents the results in tabular form. These results will be contained in an ASCII file with the extension .RE2. This file can be edited and printed using standard DOS utilities.

If the computation terminates without any errors another file (extension = .REP) which contains a description of the system status (water depths and discharges) at the end of the simulation is generated. This file could, if necessary, serve to define the initial conditions of a future simulation (parameter IFSTA = -1, as described in section 3.2b).

In addition MISTRAL also generates two binary files that can be accessed by the SIMUTRA plotter program. The first of these (extension = .TR1) is a reference file while the second (extension = .TR2) contains the water depths, discharges and velocities at each computational point and each specified computational time step.

5.2 SIMUTRA - Graphics Output

SIMUTRA is capable of making use of the information contained in the .TR1 and .TR2 output files and producing four types of graphic outputs, either on a plotter or a monitor :

- Variation of water depth with time at a given point, Z(T)
- Variation of discharge with time at a given point, hydrograph Q(T)
- Water surface profile along canal at a given instant, Z(X)
- Maximum and minimum water surface elevation, ZMAX, ZMIN

The choice of output type and device is made in an interactive mode.

The user also has the freedom to decide on the most appropriate parameters (axes, scale, labeling etc.) for each graphic output. These parameters will be included in a data file that the user will have to create, associated with each type of graphic output. These files should obligatorily be named Z(T).DON, Q(T).DON, Z(X).DON, and ZMAX.DON, as the case may be, before running SIMUTRA.

If the plotter is chosen as the output device, SIMUTRA will automatically generate HPGL plotting code. The user will again have two options:

- the default option, where the plotting is performed on-line, on a plotter connected to the serial port of the computer, or

- the file option, for which an ASCII file (the user is free to specify any name for this file) is created which can be accessed for plotting on a HPGL compatible plotter at a future time. The DOS "type" command via the COM1 serial port will be used for this purpose as follows : TYPE > COM1 'filename'.

At the end of every graphic output a file named FORT97 is automatically generated by SIMUTRA. This file can be later processed for plotter output by the PLOTGKS utility. If the user wishes to conserve this file he should remember to rename it suitably since the next run of SIMUTRA will replace the contents of FORT97 with fresh data.

VI CALIBRATION/VALIDATION

Once the model is properly coded, it will have to be calibrated by comparing model-generated output (water depths and discharges) with actually observed values under the same operational conditions. The software will then permit the user to simulate the canal response to a range of different operational scenarios as maybe appropriate to the problem under consideration. The calibration will be carried out once water issues commence during the next

(<u>Maha</u>) cultivation season.

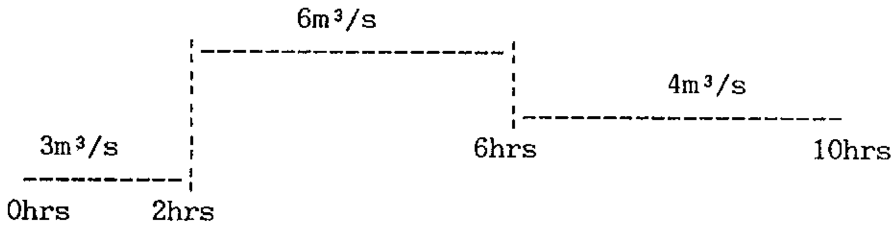
VII SAMPLE OUTPUT AND DISCUSSION OF RESULTS

A test application of the MISTRAL/SIMUTRA software was made on the first reach of the Kalankuttiya branch canal. In the absence of real topographical data, design cross sections were assumed. Canal bed levels were obtained from a partially completed longitudinal survey carried out by the Mahaweli Economic Agency about two years ago[2]. A Strickler roughness coefficient of 25 was applied throughout the branch canal except at the rocky constriction where a value of 20 was applied.

Theoretical head-discharge relationships taken from the literature are assumed to describe the flow through the rocky constriction and over the duck-bill weir.

A set of equations relating branch canal water depths and offtake gate openings to distributory canal discharges are also derived for each size of gate present in the system. The equations were checked against actual field observations of these three variables and were found to be adequate.

The outputs obtained correspond to an imaginary manipulation (sudden opening followed by a sudden partial closure) of the sluice gate at the head of the branch canal of the following form:



All the branch canal gates are assumed to be fully opened.

It should be noted that the attached graphic outputs (Figures 3, 4, 5 and 6) are in fact hard copies of the outputs generated on the monitor, having been obtained on a dot-matrix printer using the "print screen" command. This was the only alternative available, in the absence of a plotter. It is hoped that it will be able to produce outputs of better quality once a proper HPGL compatible plotter is procured.

Figure 3 shows the variation of water level at various computational points

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[2] The results of the fresh topographical survey commissioned by IIMI will be available soon. It will then be possible to reconstruct a model that represents the real canal features more accurately.

in the branch canal. The points considered are :

- Point P1, just downstream of the head sluice;
- Point P2, close to distributories 305D1 and 308D1;
- Point P10, close to distributory 305D2;
- Point P15, close to distributory 305D3;
- Point P18, close to distributory 308D2;

It is observed that the response to the above manoeuver at P1 and P10 is nearly instantaneous. The points further downstream take longer to respond fully. The time of propagation is seen to be around 2 hours. Furthermore, it will be observed that the rise in branch canal water level close to the duck-bill weir (points P15 and P16) is much less than at the points further upstream. This is a clear demonstration of the regulating effect of the duck-bill weir.

The impact of varying branch canal water levels on discharge into the distributory canals is illustrated in Figure 4. The discharge values carry a negative sign since, for computational reasons, all offtakes are considered as tributaries with negative inflows (see also section 4.1). Their absolute values however represent the actual flow through the distributories. As might be expected, the greatest variation in discharge occurs in the two uppermost canals, 305D1 and 308D1. The offtake of 305D1 consists of two pipes of 60 cm diameter each and is capable of accomodating a major portion of the increased discharge in the branch canal. Though canal 308D1 is subject to the identical change in head as 305D1, the resulting change in its discharge is much less (nearly half) than that occuring in 305D1. This is due to the fact that the 308D1 offtake consists of only a single 60 cm diameter pipe. The smallest change in discharge is recorded by distributory canal 308D2 (closest to the duck-bill weir), followed by 305D3 and 305D2. The absolute discharge in 305D3 is greater than that in 305D2 and 308D2 because 305D3 has a 60 cm diameter offtake while the latter two are of 45 cm diameter.

These observations further highlight a danger that one should guard against when operating the Kalankuttiya branch canal. That is, the two uppermost canals have the capacity to take a large proportion of the branch canal flow, and if their gate openings are not properly monitored the water available to the lower reaches of the system could be adversely affected, both in terms of adequacy and timeliness of deliveries.

Figure 5 shows water surface profiles obtained at different times in the branch canal. Again it will be noted that the fluctuations in branch canal water levels are smallest in the proximity of the duck-bill weir. Another interesting feature that comes to light is the head loss (as much as 30 cm) that occurs due to the rocky constriction. The effect of enlarging this section on flow propagation can easily be simulated.

It will also be observed that at a discharge of $6 m^3/s$ the branch canal is close to overtopping its embankments. This will give the user an indication of the discharge capacity of the canal, all the offtake gates in the first reach being fully open. Note that the value of $6 m^3/s$ is close to the

$5.66 m^3/s$ value cited as the branch canal design capacity in section II.

It is emphasized that the above outputs and discussion might not be a true representation of reality and are only indicative. They will have to be verified once the model outputs are properly validated by field observations. Nevertheless the objective was to describe some of the model outputs and to discuss possible interpretations of the results.

We shall conclude with a chapter highlighting some of the potential uses to which the MISTRAL/SIMUTRA software could be put.

VIII POTENTIAL USE OF SOFTWARE

It should be clearly understood that the MISTRAL/SIMUTRA software is not intended to perform optimization or feedback control. That is, the 'optimum' decision (e.g. offtake gate settings) under a given scenario of water supply and demand will not be automatically furnished. But rather, the consequences of different operational decisions could be evaluated via simulation.

The software therefore constitutes a simulation tool. Once it has been properly calibrated to the physical conditions of a particular canal, the software could be used to simulate its behavior under various operational scenarios. It could also be employed to study the impact of natural or artificial modifications to the canal topography (including maintenance, or lack of it) on flow propagation, effect of different designs of regulating structures, impact of interventions (authorized or unauthorized) on water conveyance and distribution.

We have restricted the use of the software in the first instance to the main conveyance system, the branch canal in the case of Kalankuttiya. It is however entirely within the capacity of the software to also incorporate the lower order canals too. Some specific applications that the software could have in the Kalankuttiya branch canal are:

1. Evaluating the maximum possible flow that the branch canal can carry without overtopping its bunds under different operational scenarios. The consequences of modifications in canal roughness coefficients as a result of lack of maintenance or other topographical changes can also be studied.

2. Demonstrating the variations in water depths and discharges (especially under transient conditions) at different points in the branch canal and the distributory canal offtakes in response to different scenarios of gate settings and water releases at the head sluice.

3. Demonstrating the effect of existing regulating structures. In Kalankuttiya, for example, the capacity of the duck-bill weirs to attenuate fluctuations in hydraulic head arising from fluctuations in branch canal discharges can be easily demonstrated. Discharges into distributory canals close to the weirs are less affected than those further away.

4. Evaluating the impact of alternative design options for regulating structures. For example, the effect of replacing the conventional gated pipe outlet at the head of a distributory canal with a calibrated module distributor, especially in the case of canals relatively uninfluenced by the presence of any other form of hydraulic head control.

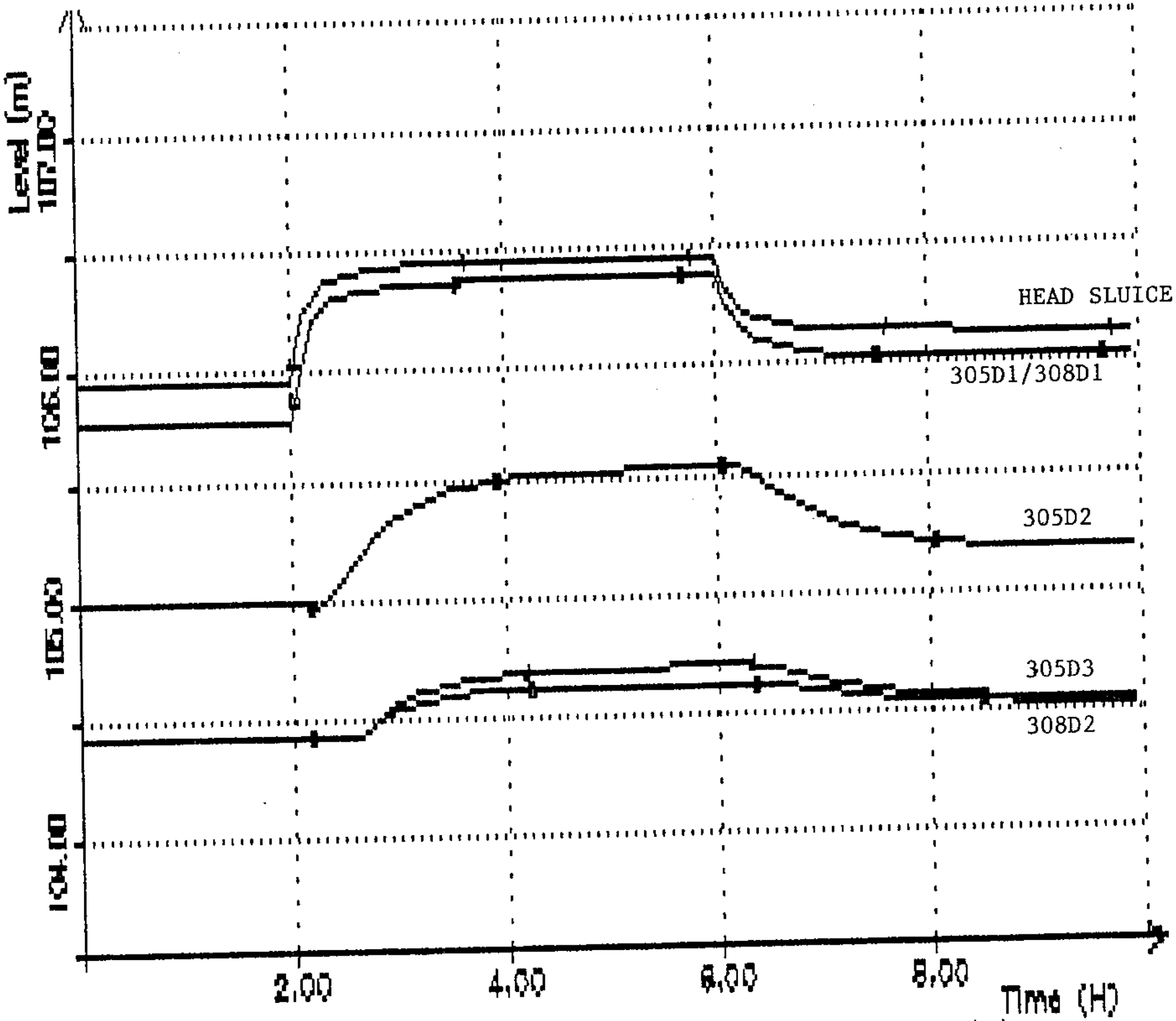
5. Developing a set of operational scenarios that would ensure equity and adequacy of water supply by studying propagation times (especially to the unregulated tail end reach of the branch canal), time taken to attain full supply depths (FSD) at the different offtakes etc.

6. Studying the potential for making more efficient use of the available water -- could any water saved in the Maha (or wet) season result in greater cultivated extents in the following Yala (or dry) season? Since the Kalankuttiya tank itself is too small to accommodate any carryover storage, this may have to be evaluated at the higher levels within the Mahaweli System H.

7. Using the software as a training tool. On the one hand, irrigation agency staff could familiarize themselves with the system much faster, get a broader perspective of the system behavior and experiment with a far wider range of operational scenarios than would be possible on the field. On the other hand IIMI could develop training material based on a real-life project for the purpose of professional development in the field of system modernization, and initiation in canal regulation technologies and practices.

ACKNOWLEDGEMENTS

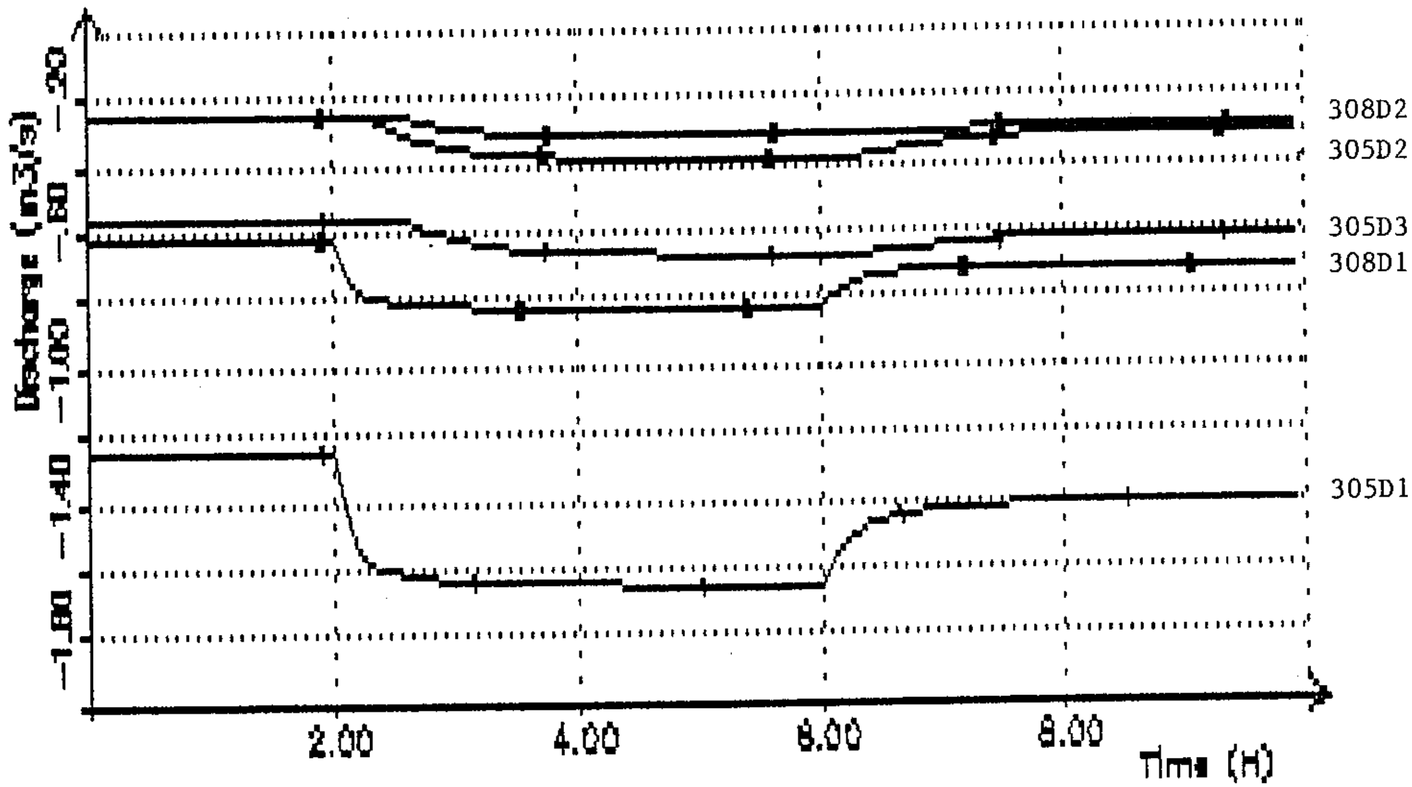
The professional yet friendly interaction with Alain GUEGUEN in setting up this application was very rewarding and is gratefully acknowledged.



KALANKUTTIYA 1st Reach – Graph Z(T)

(VARIATION OF WATER LEVELS WITH TIME)

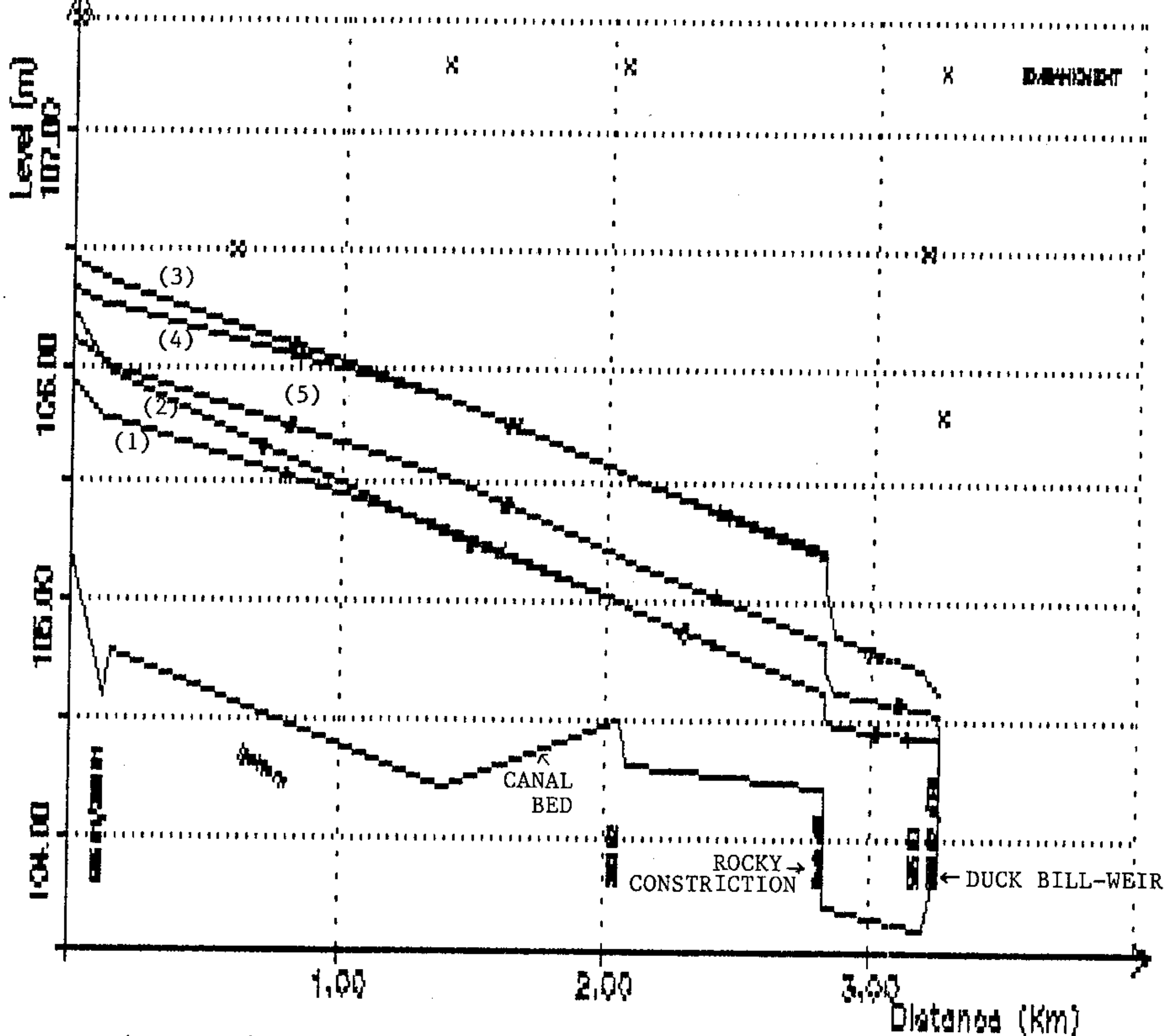
FIGURE 3



KALANKUTTIYA 1st Reach - Graph Q(T)

(VARIATION OF DISTRIBUTORY CANAL DISCHARGE WITH TIME)

FIGURE 4

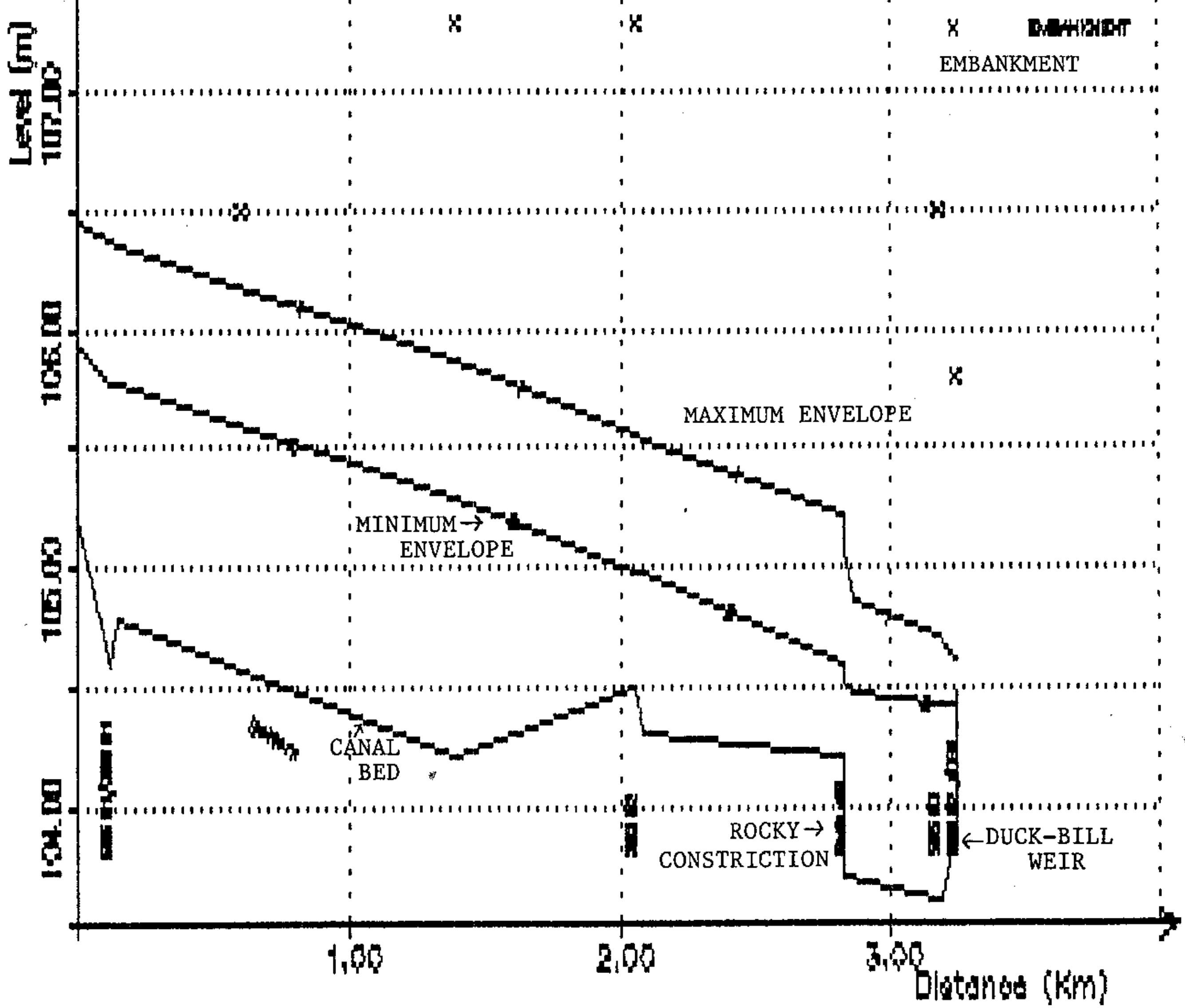


KALANKUTTIYA 1st Reach - Graph Z(X)

(WATER SURFACE PROFILES)

FIGURE 5

Legend : (1) - 2 hours
(2) - 2.1 hours
(3) - 6 hours
(4) - 6.1 hours
(5) - 10 hours



KALANKUTTIYA 1st Reach - Graph ZMAX

(ENVELOPES OF MAXIMUM & MINIMUM WATER SURFACE PROFILES)

FIGURE 6