IIMI Working Paper No. 9

MATHEMATICAL MODELING OF IRRIGATION CANAL SYSTEMS

PART I. PRESENTATION OF THE "MISTRAL-SIMUTRA" SOFTWARE PACKAGE

PART II. APPLICATION OF "MISTRAL-SIMUTRA" TO THE KALANKUTTIYA BRANCH CANAL (MAHAWELI SYSTEM H), SRI LANKA

Daniel Berthery, Hilmy Sally, and Jayantha Arumugam

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We also thank those IIMI staff members who provided useful suggestions to improve earlier drafts of this paper, many of which have been incorporated in this present version.

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PREFACE

This two-part Working Paper presents the interim results of IIMI's first attempt to use mathematical modeling as a methodology to investigate main canal operations and to conduct research on the interactions between design and management at that level of an irrigation system.

This study was initiated in September 1987, thanks to the assistance of the Societe Crenobloise d'Etudes et d'Applications Hydrauliques (SOGREAH), the French firm of consulting engineers, which made available to IIMI a software package -- MISTRAL-SIMUTRA -- for simulation of steady and unsteady flow in open channels. MISTRAL is actually a simplified microcomputer version of CARIMA, a sophisticated and powerful simulation software that runs on a mainframe computer. The program was developed by the firm in the 1970s to study the impact of natural or artificial modifications introduced in rivers and their associated flood plains, with a view to evaluating the impact of flood routing and for the management of regulating reservoirs in particular.

The application of mathematical modeling conducted by IIMI on the Kalankuttiya Branch Canal, being IIMI's first case study of that nature, is relatively modest in its objectives:

First, the study aims to demonstrate, through the model, the impact of the particular regulating structures present here -- fixed duck-bill weirs -- on the control of water levels along the various reaches of the branch canal' arid thereby on the control of the discharge diverted at the offtakes nearby.

Second, it is expected that, with proper calibration, the model will contribute to the identification of timely operations of the system (main sluice and offtakes) to manage the rotational pattern of water releases in the branch canal followed by its closure, which constitutes the current operational practice of the irrigation agency, more efficiently, (e.g., ensuring equitable distribution of water while minimizing operational losses or shortage at the tail).

The first objective has already been achieved. Even though the model has not yet been calibrated beyond the first reach, the computation of water surface profiles in the branch canal for a range of inflows under steady flow conditions brings to light the differences that exist between offtakes in terms of level control in the parent canal, depending on their location with respect to the regulating structure.

The calibration of the entire canal is underway and the water level and flow data required for this purpose have been collected during yala (dry season) 1988. Flow simulations under unsteady conditions similar to those that are created when the main sluice of the canal is opened or closed can then be performed, thus permitting the achievement of the second objective.

Perhaps the greatest benefit of the application so far has been the opportunity provided to IIMI staff to familiarize themselves with the modeling approach and with the numerical hydraulic techniques involved. It is however planned to develop the application further to the point of being able to propose, to the irrigation agency, effective strategies for managing the Kalankuttiya branch canal. Conducting this application has also helped IIMI to formulate the term of reference for a mathematical model tailor-made to cater to the needs of IIMI's multidisciplinary staff in carrying out research on exploring the prospects for more effective and responsive canal operations. Such a model is currently under development for the Kirindi Oya Right Bank Main Canal in southern Sri Lanka.

Part I of this Working Paper deals with the description of the MISTRAL-SIMUTRA software package, its data requirements and output, and its potential use as a research, operational and training tool.

Part II reports the preliminary results obtained in applying the MISTRAL-SIMUTRA software to modeling the behavior of the Kalankuttiya branch canal in north-central Sri Lanka. These results are compared with field observations and the impact of the particular design features of the system on canal operations is highlighted.

PART I

PRESENTATION OF THE "MISTRAL-SIMUTRA" SOFTWARE PACKAGE

INTRODUCTION

The management of water delivery constitutes one of the major themes around which IIMI articulates its research programs.

Current operational practices in the large open canal networks of many irrigation systems of Asia suggest that there is considerable potential for the development of effective and responsive main system management (Chambers, 1988). Operational practices are however also conditioned by the particular design features for water level control in the main conveyance system and discharge control at their offtakes. Efficient management of water conveyance over long distances in main canals and into distributary canals suffers due to the lack of, or ineffective, control facilities provided for in the design of the system. Hence IIMI's research agenda under the above theme also includes analyzing the interactions between the design and the management of main irrigation canals.

Research into the developnent of innovative main system design and management practices through field experimentation on live irrigation systems is seldom a feasible option -- too many people would be inconvenienced and crops adversely affected. Even if it were possible to overcome these conditions the dimensions of the canal concerned and the dynamics of the system would make the exercise laborious and generally not replicable. In fact some experiments would be dangerous to perform, such as operating the main canal at maximum conveyance capacity, since this could lead to considerable losses of water, not to speak of the potential threat to the structural integrity of the canal itself.

Off-the-field techniques of assessing system behavior such as mathematical modeling thus become a viable alternative to direct experimentation on the physical system. However, the validity of any model depends on the degree of accuracy with which it represents the real system. In the case of a canal all hydraulically significant features should be identified and adequately represented in the model. This can only be ensured via appropriate data gathering and adequate calibration of the model to actual field conditions. A mathematical model cannot thus be properly constituted entirely independent of field work.

The implementation of mathematical modeling techniques is often synonymous with computer use. In fact, developnents in the field of mathematical modeling closely follow advances in computer technology. The advent of more powerful and relatively inexpensive computers has brought them within the reach of irrigation agencies in developing countries.

IIMI's choice of mathematical models for flow simulation as research tools for addressing the issue of design and management interactions in identifying effective and responsive main system operations is thus not inappropriate.

The general procedure for building a computer model could be broken down into a number of phases, each of which influences the performance of the succeeding phase:

1. Defining a suitable algorithm. This is a step by step analysis of the problem and its solution. This phase requires a thorough understanding of the problem at hand, a careful examination of the inputs required, and *the* expected output.

2. Translating the algorithm to a high-level computer language such as BASIC, FORTRAN, PASCAL etc. resulting in a 'computer program'.

3. Compiling/Interpreting the above program to a low-level machine language which can then be understood by the processor. This stage may be machine-dependent unlike the previous one.

4. Test-running the program on a model for which input and output data sets are available; to ensure that the model is working properly, the model outputs are compared with the output data set already available.

5. Representing the physical system to be studied in the model and calibrating it for specified field conditions.

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 equations 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 *goals* in research, information dissemination and 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 sought the assistance of the French consulting firm, SOGREAH, to procure their microcomputer software package "MISTRAL-SIMUTRA" for flow simulation in canals. The first application of mathematical modeling using this software was conducted on the Kalankuttiya branch canal within the Mahaweli System H in the North-Central Province of Sri Lanka (Figures 1 and 2).

The purpose of this paper is to describe the software, its data requirements, output, and potential use in identifying effective and responsive main system operations.

SOFTWARE DESCRIPTION

The simulation software consists of two distinct modules:

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

Figure 1. Location map of Mahaweli Systems.

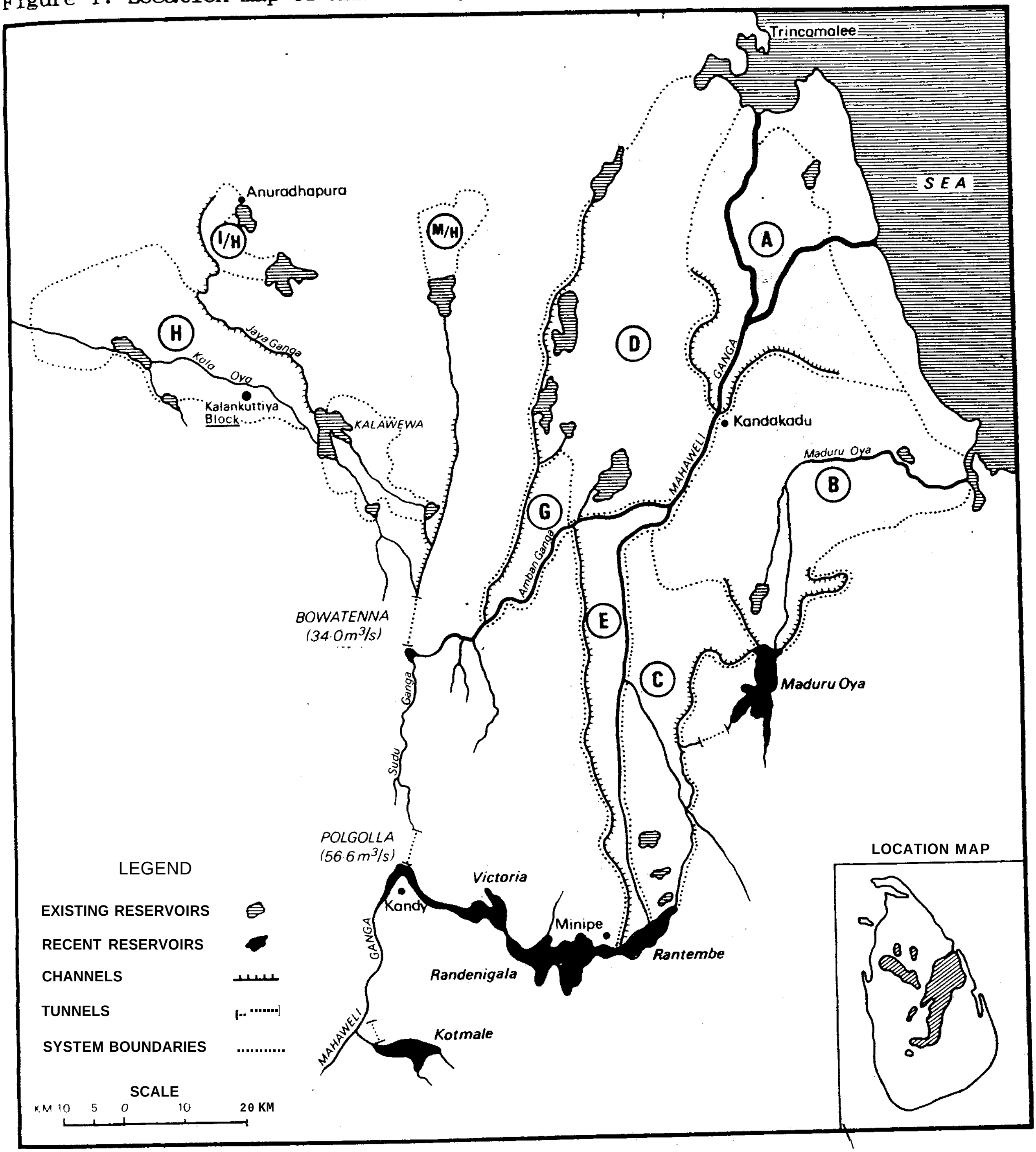


Figure 2. Kalankuttiya Block of Mahaweli System H.

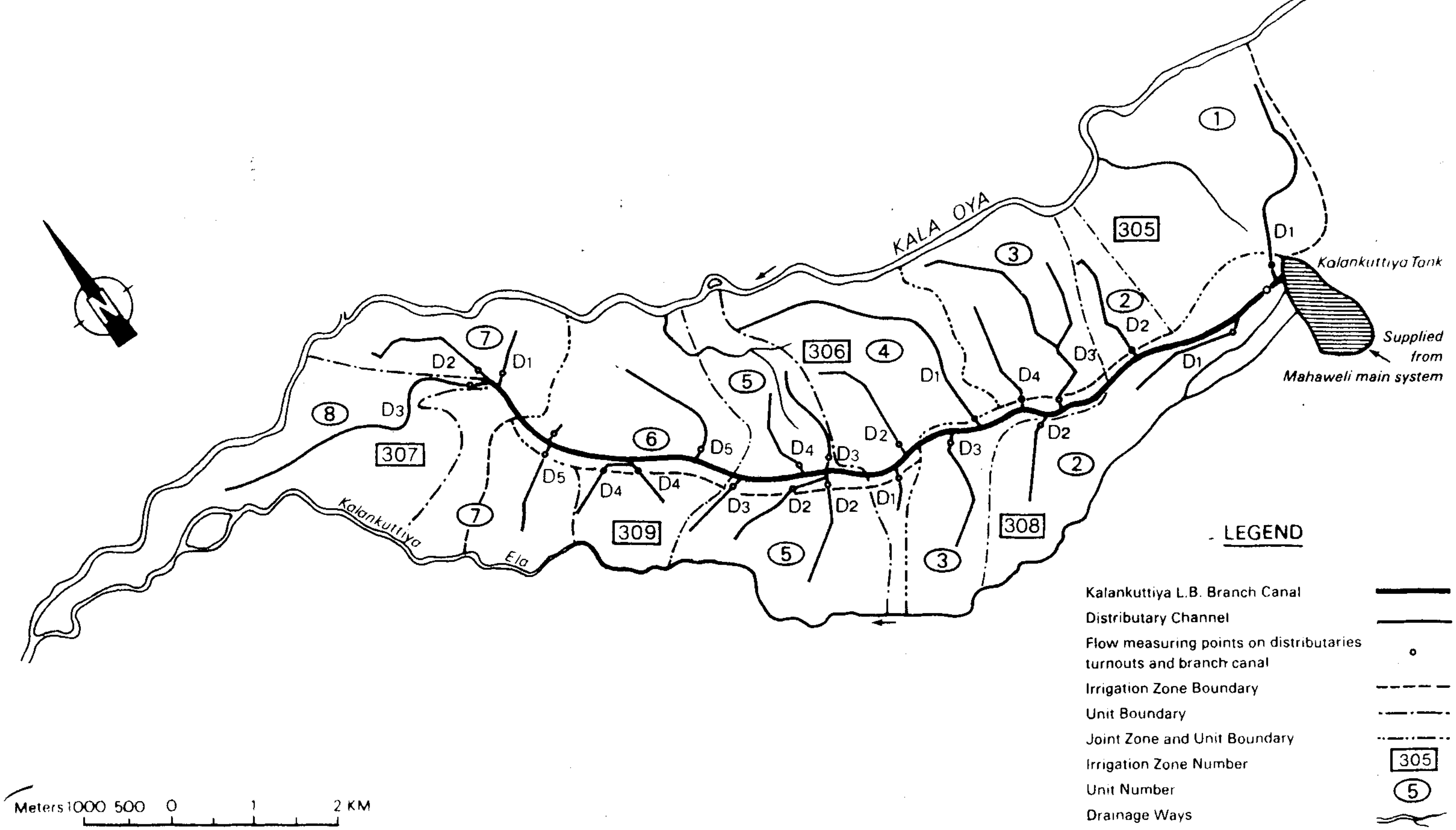
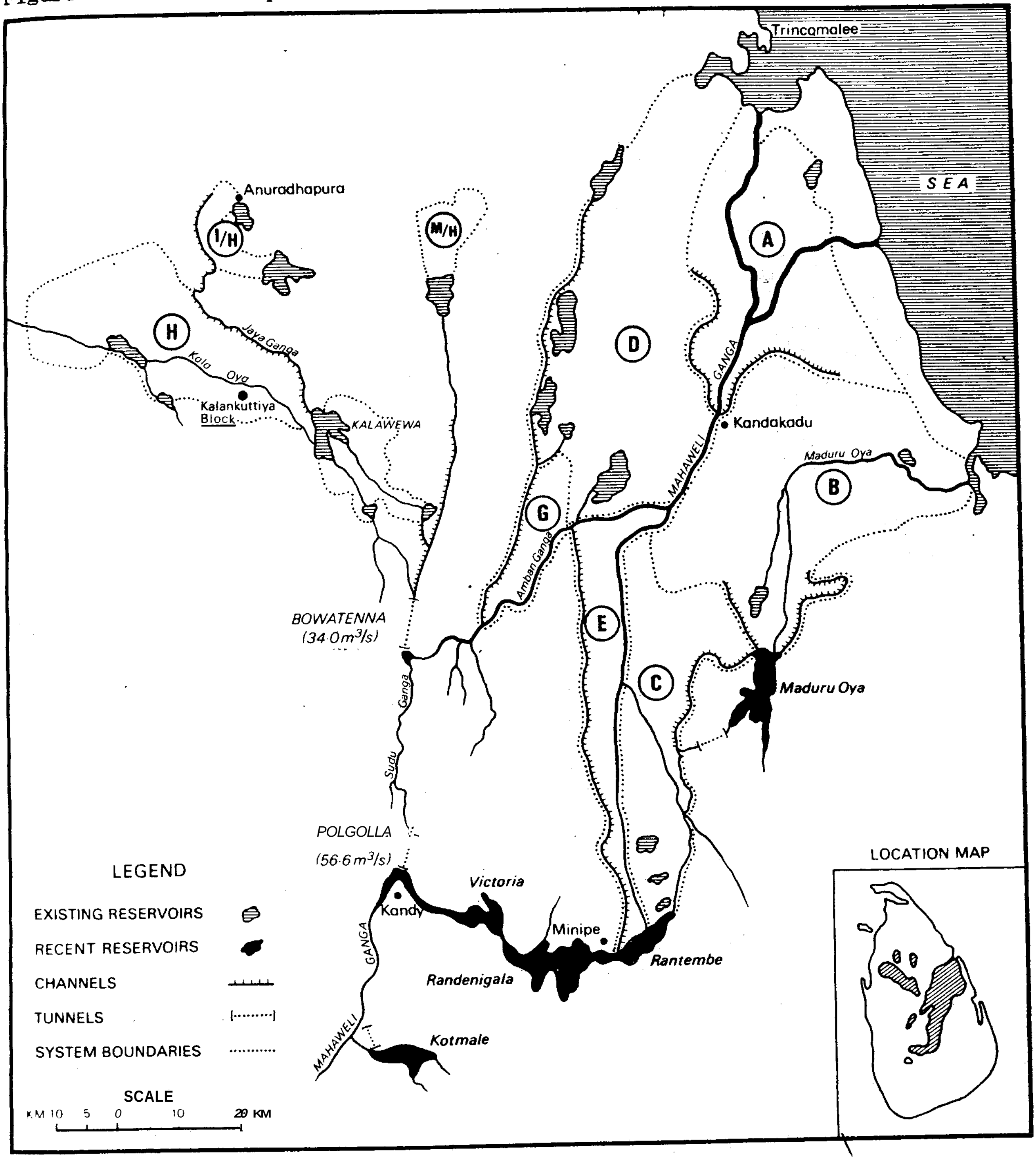


Figure 1. Location map of Mahaweli Systems.



The source programs are written in MS-FORTRAN 77. IIMI has acquired compiled versions of these programs which are thus directly executable. Hence only the final phase indicated above, that of representing the canal system in the model and calibrating .it for a given set of field conditions, need be performed.

The minimum hardware configuration needed for running these programs is:

- IBM-PC/XT computer (or compatible) with 640KB RAM, 20MB hard disk and Math Co-processor
- Monitor with Color Graphics Adapter
- Printer (preferably 132 columns)
- HPGL compatible plotter (e.g., HP 7475 plotter)

For greater efficiency an IBM-PC/AT (or compatible) computer with an Enhanced Graphics Adaptor is recommended.

MISTRAL itself *acts* in two phases, a model coding phase and a calculation phase. Each phase requires a specific input file, a model configuration file (phase 1) and a calculation file (phase 2). In the model coding phase the program analyzes the data pertaining to the canal topography and the hydraulic characteristics of the structures, contained in the model configuration file, and transforms these data into a set of coded instructions that *can* be easily accessed during the calculation phase. Before executing the second phase, the user is required to create a calculation file describing the precise type of scenario to be simulated. The calculation phase involves the numerical resolution of the Barre de St Venant's equations[1] by means of an implicit finite difference technique. The output essentially consists of the water level, discharge, velocity and flow volume at each computational point.

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

The general procedure for use of the MISTRAL-SIMUTRA programs is described schematically in Figure 3.

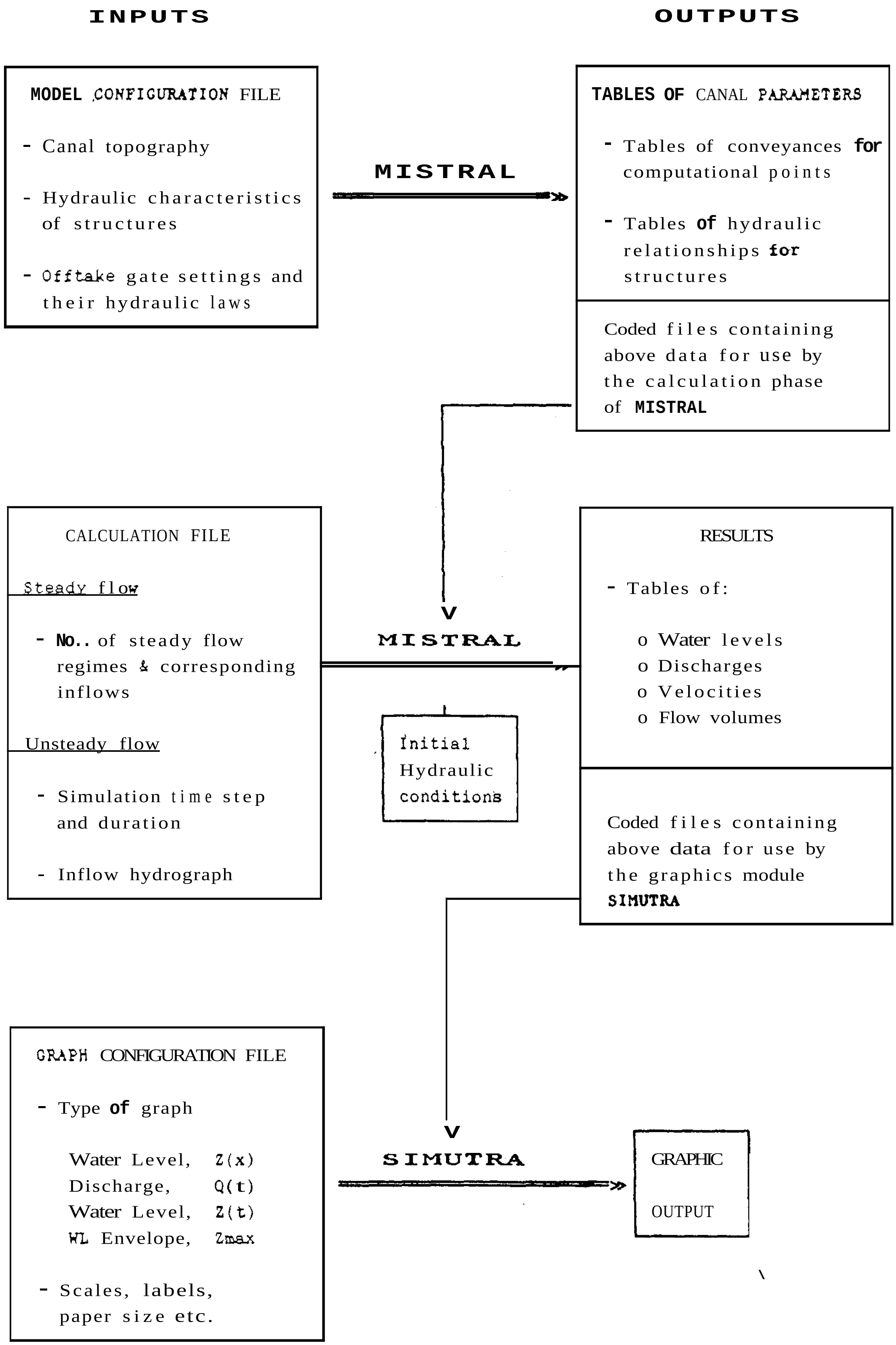
The version of MISTRAL used by IIMI has a capacity equivalent to 100 computational points. The number of computational points for any given model depends on the number of structures and singularities that have to be represented. For example, a *canal* with frequently varying topography would require a large number of computational points. Similarly *the* higher the number of structures such as regulators, offtakes, etc., the higher the number of computational points required.

SOFTWARE INPUT

Canal Topology

The first step is to describe the *canal* to be modeled in such a manner that it's physical features are represented to the required degree of

Figure 3. MISTRAL/SIMUTRA program use.



accuracy. The MISTRAL-SIMUTRA programs are capable of modeling fixed Structures, for example, 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 which be used as an example to illustrate the use of the software:

Upstream head sluice; a boundary condition in terms of 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); these 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 (duckbill 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., up to the first duckbill 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   :    GATE/              :              CONSTRICTION   : BRIDGE   DUCK
SLUICE :    BRIDGE   BRIDGE    :      BRIDGE                 :          BILL
      305D1                  305D2                         305D3        WEIR
```

The corresponding topological (branch and node) representation of this reach of canal is indicated in Figure 4. The symbol █ represents the computational points, appropriately labeled.

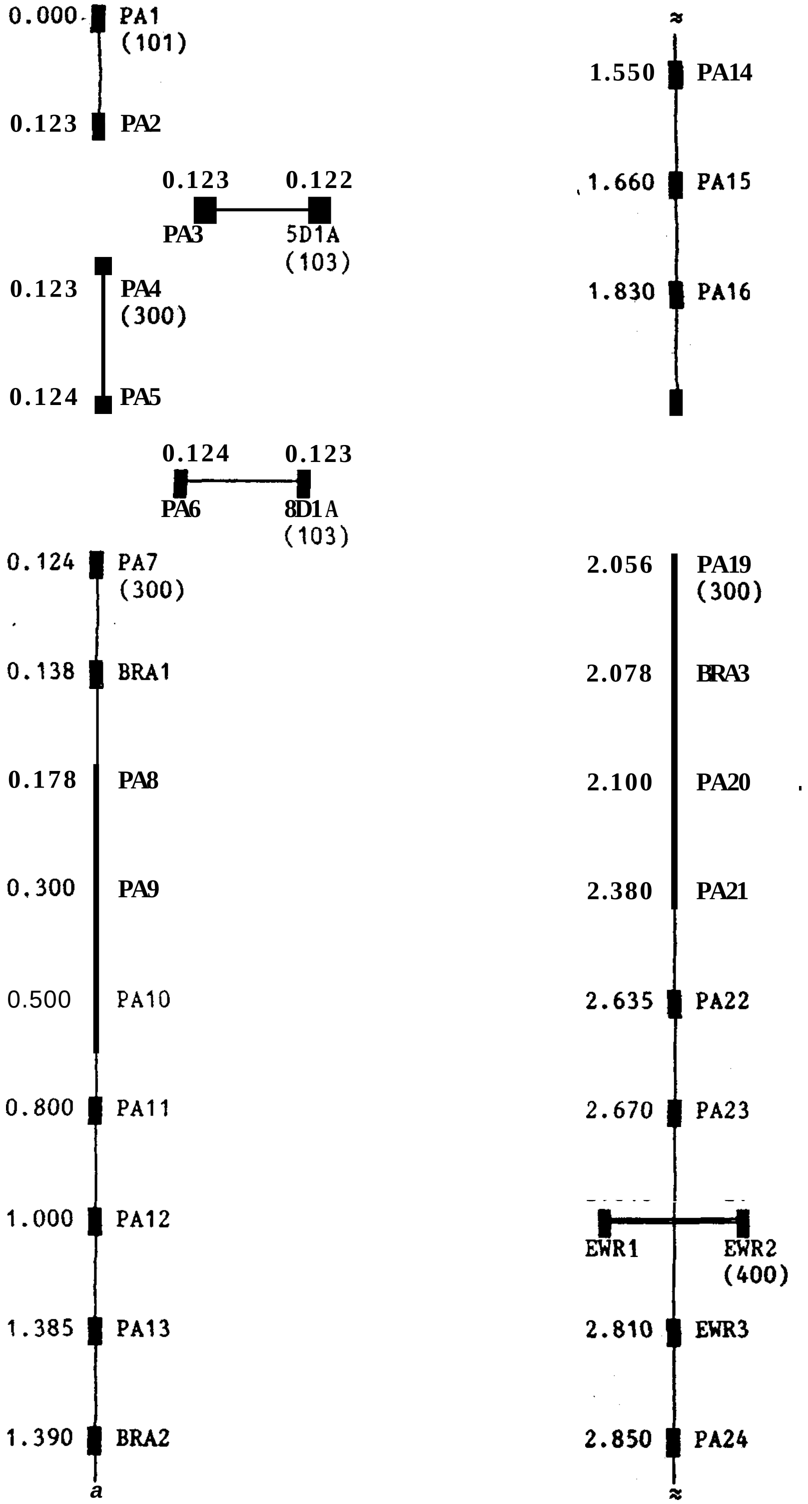
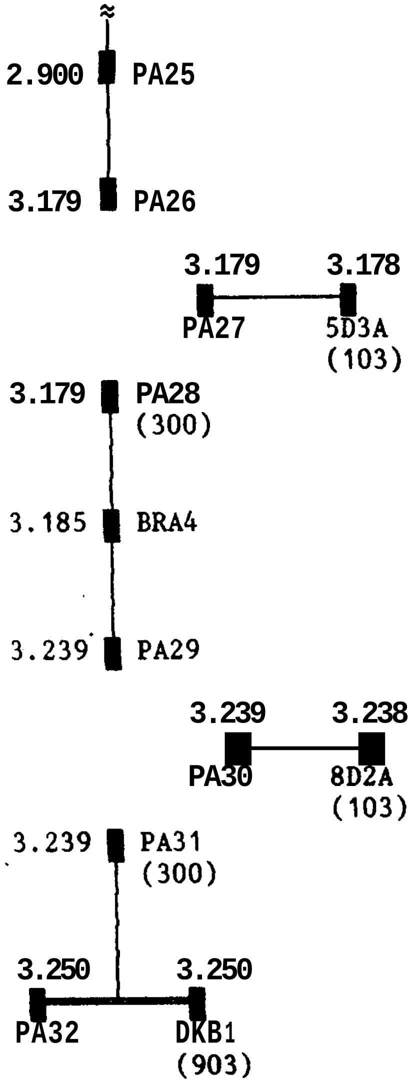


Figure 4. Schematic diagram of computation points in first reach.

(Continued...)


2.900
PA25
3.179
PA26
3.179
3.178
PA27
5D3A
(103)
3.179
PA28
(300)
3.185
BRA4
3.239
PA29
3.239
3.238
PA30
8D2A
(103)
3.239
PA31
(300)
3.250
3.250
PA32
DKB1
(903)

The following convention was adopted for the nomenclature:

1. Normal sections, (e.g., PA10)

First character	(P)	: Intermediate point
Second character	(A)	: Represents the reach; A refers to reach 1,. B refers to reach 2, and so on.
Next one or two characters	(10)	= Number of the computational point in that reach

2. Bridges, (e.g., BRA3)

First two characters	(BR)	= Stands for BRidge
Next character	(A)	= Represents the reach as above
Next character	(3)	= The number of the bridge in that reach

3. Distributary canal offtakes, (e.g., 5D2A)

First character	(5)	: Stands for irrigation block 305
Next character	(D)	: Stands for Distributary canal
Next character	(2)	= Number of the distributary canal
Next character	(A)	= Represents the reach as 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 distributary canal 305D2 is represented by the points PA17, 5D2A, PA18, and PA19 in that order.

4. Duckbill weirs; e.g., DKB1 refers to the first duckbill weir, etc.

5. EWR1, EWR2, EWR3 (standing for Equivalent WeiR) are three computational points employed to account for the hydraulic head loss that occurs 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 downstream 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 a) tributaries or offtakes since discharges into and out of the modeled canal can only occur at nodes, or b) any of the other topological features listed above.

The numbers against each computational point (e.g., *0.500* against PA10 and 1.390 against BRA2) represent the distance in kilometers to that point from the head of the canal.

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

code **101**: Defines the upstream boundary condition expressed in **terms** of a function relating discharge and time.

Code 102: Defines the upstream boundary condition **expressed** in terms of a function relating **water** level 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 distributary canal offtake discharges should be given a negative **sign**.

code 300: Endicates 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 distributary *canal* 305D2, the code 300 is used to indicate that the computational point **PA19** should be associated with the upstream point PA17.

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** is used at the first duckbill 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).

Complete explanations of the significance of the codes are contained in the MISTRAL Users' Manual.

Preparation of Input Files

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** that define a given state are descriptions of the canal topography (distances, 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 would usually remain 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 creates the user should adopt the extension .DON (from donnee or data in French). For example, the model configuration files created for modeling different states of 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 files, (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 (parameter IFMOD = 2) the coded data Gill be conserved in a binary file under the corresponding name but with the extension .MOD (e.g., 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 latter 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 an appropriate calculation file with IFMOD = 4 *(see* next section).

The flow chart (Figure 5) gives an overview of the functioning of the MISTRAL software.

<u>Calculation file</u>. 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.

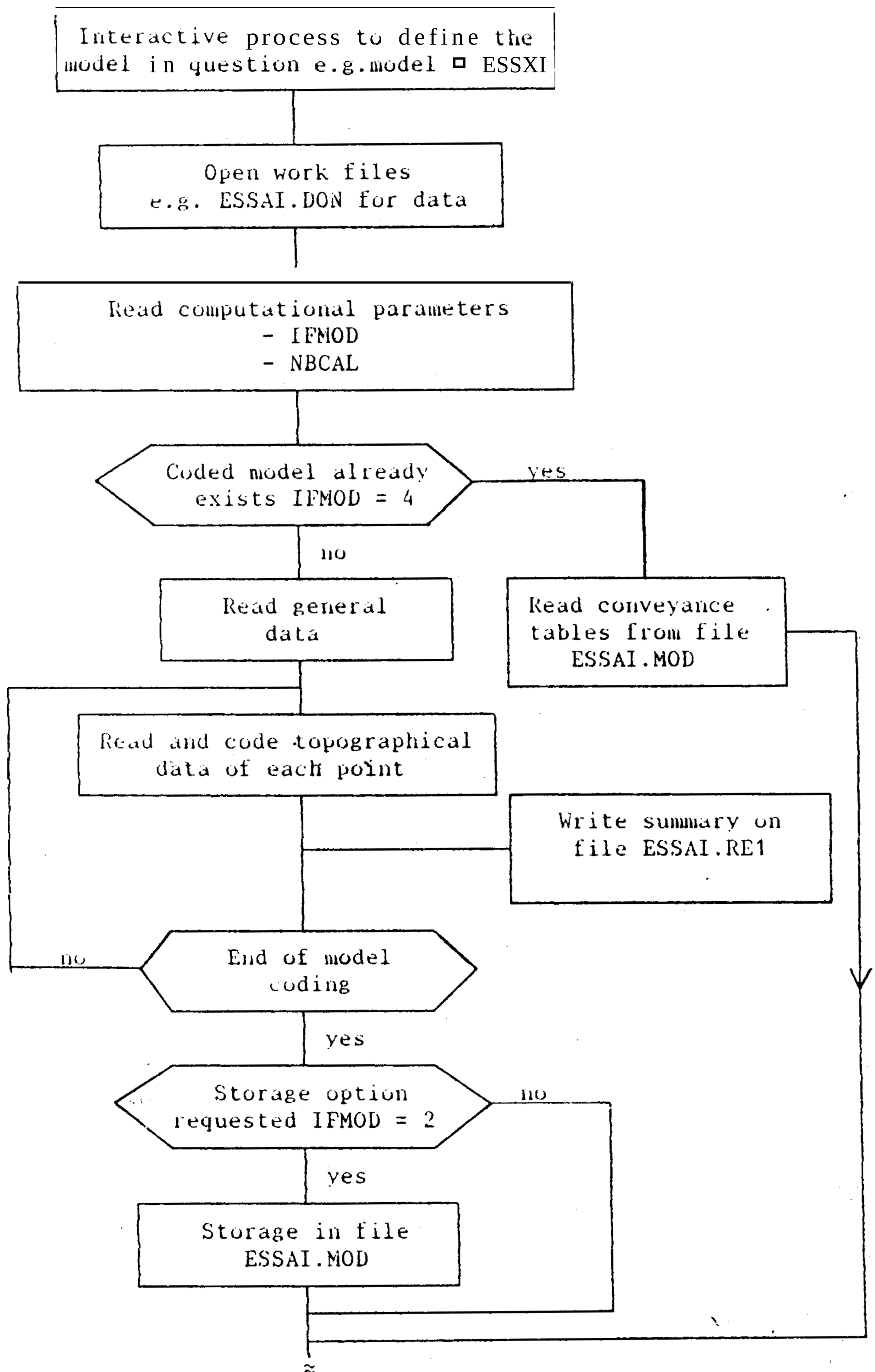
The calculation data file contains information on the hydraulic flow regime (steady or unsteady) to be simulated, the time step and duration of the simulation, the frequency of edition and storage of the results, and the mode of initial stabilization to be adopted.

In respect of initial stabilization the user has three options, defined by the value attributed to the parameter IFSTA:

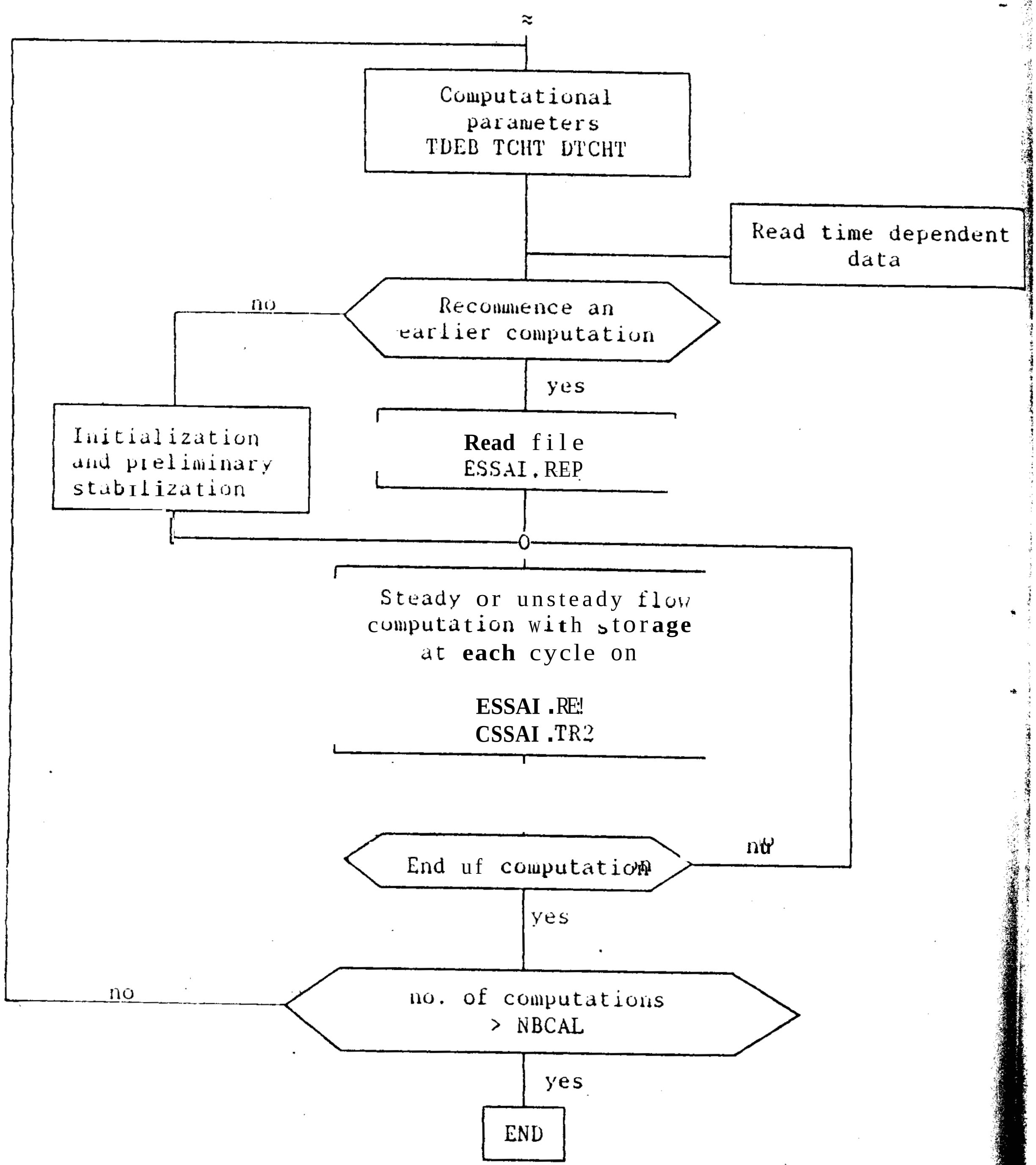
1. IFSTA = *0*, impose as initial conditions the depths and discharges in computer memory, resulting from the computation immediately preceding the present one;

2. IFSTA = 1, allow the program to perform a default stabilization procedure; or

Figure 5. Flow chart of the functioning of MISTRAL software.



(Continued...)


Computational parameters TDEB TCHT DTCHT
Read time dependent data
Recommence an earlier computation
no
yes
Initialization and preliminary stabilization
Read file ESSAI.REP
Steady or unsteady flow computation with storage at each cycle on
ESSAI.RE!
CSSAI.TR2
End of computation
no
yes
no. of computations > NBCAL
no
yes
END

3. 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; also see next section), 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 with the corresponding name KACAL001.MOD. Before running MISTRAL with the calculation data file KACAL001.DON, the user should therefore ensure that the relevant 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 have been 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.

SOFTWARE OUTPUT

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 the preceding section).

In addition MISTRAL, also generates two binary files that can be accessed by the SIMUTRA graphic output 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.

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 on 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** dong canal at a given instant, Z(X)
- Maximum and minimum water surface elevations, ZMAX and 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 associated with each type of graphic output, that the user will have to create. 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 <u>default</u> 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 "TYPE" or "PRINT" **commands** of DOS via the COM1 serial port can be used for this purpose as follows: <u>TYPE > COM1 'filename'</u>, or <u>PRINT 'filename' /d:COM1:</u>

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 remembering to rename it suitably since the next run of SIMUTRA will replace the contents of FORT97 with fresh data;

CALIBRATION AND 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 may be appropriate to the problem under consideration. The calibration carried out in respect of the first reach of the Kalankuttiya branch canal is described in Part II of this Working Paper.

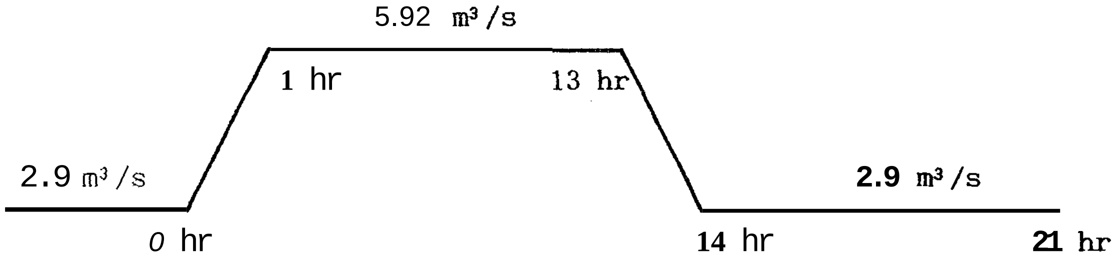
SAMPLE OUTPUT AND DISCUSSION OF RESULTS

A test application of the MISTRAL-SIMUTRA software **was** made on the first reach of the Kalankuttiya branch canal. Topographical data was gathered in the course of a specially commissioned survey of the Kalankuttiya branch canal in late 1987. A Strickler roughness coefficient of **30** was applied throughout the first reach. \

Theoretical head-discharge relationships taken from the literature are assumed to describe the flow through the rocky constriction and over the duckbill weir (see also Part II of' this Working Paper).

A set of equations relating branch canal water depths and offtake gate openings to distributary 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 found to be adequate.

In the sample application, all the branch canal gates are assumed to be half-opened. 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 (the rationale for the choice of these discharge values is described in Part II of this Working Paper):



The four types of graphic outputs possible are given in Figures **6**, **7**, **8**, and **9**. Sample numerical output (at time 1.50 hours) is indicated in Table 1.

Figure 6 shows the temporal variation of water level at various computational points in the branch canal. The points considered are :

- Point PA1, just downstream of the head sluice
- Point **PA3**, at the offtake of distributary 305D1
- Point PA6, at the offtake of distributary 308D1
- Point PA18, at the offtake of distributary 305D2
- Point PA27, at the offtake of distributary 305D3
- Point PA30, at the offtake of distributary 308D2

The response to the above maneuver at the head sluice and 308D1 is nearly instantaneous. The points further downstream take longer (almost one hour) to respond fully. Furthermore, the rise in branch canal water level close to the duckbill weir (points **PA27** and PA30) is much less than further upstream. This is a clear demonstration of the regulating effect of the duckbill weir.

The impact of varying branch canal water levels on discharge into the distributary canals is illustrated in Figure 7. The discharge values carry a negative sign since, for computational reasons, all offtakes are considered as tributaries with negative inflows. Their absolute values however represent the actual flow through the distributaries. As might be expected, the greatest variation in discharge occurs in the two uppermost canals, 305D1 and 308D1. But although the 308D1 offtake is subject to the identical change in head as

Table 1. Flow parameters at time = 1.5 hours.

Point	Discharge (m³/s)	Water level (m)	Velocity (m/s)	Volume ('000 m³)
PA1	5.92	106.42	.80	0.
PA2	5.89	106.36	.49	1.
5D1A	-1.13	106.36	-.09	1.
PA3	-1.13	106.36	-.09	1.
PA4	4.76	106.36	.40	1.
PA5	4.76	106.36	.40	1.
8D1A	-.52	106.36	-.04	1.
PA6	-.52	106.36	-.04	1.
PA7	4.24	106.36	.35	1.
BRA1	4.24	106.34	.68	1.
PA8	4.23	106.32	.60	2.
PA9	4.21	106.27	.52	3.
PA10	4.16	106.20	.56	4.
PA11	4.06	106.10	.43	7.
PA12	3.97	106.06	.36	9.
PA13	3.77	105.90	.57	12.
BRA2	3.76	105.90	.45	12.
PA14	3.68	105.87	.39	14.
PA15	3.63	105.76	.84	14.
PA16	3.54	105.63	.47	15.
PA17	3.37	105.58	.35	17.
5D2A	-.32	105.58	-.03	17.
PA18	-.32	105.58	-.03	17.
PA19	3.05	105.58	.32	17.
BRA3	3.04	105.58	.41	17.
PA20	3.02	105.57	.37	18.
PA21	2.76	105.52	.29	20.
PA22	2.56	105.45	.47	22.
PA23	2.53	105.44	.35	22.
EWR1	2.39	105.41	.26	23.
EWR2	2.39	105.41	.26	23.
EWR3	2.39	104.68	.36	23.
PA24	2.37	104.67	.36	24.
PA25	2.36	104.65	.49	24.
PA26	2.31	104.55	.39	25.
5D3A	-.45	104.55	-.08	25.
PA27	-.45	104.55	-.08	25.
PA28	1.86	104.55	.32	25.
BRA4	1.86	104.55	.35	25.
PA29	1.85	104.54	.23	26.
8D2A	-.24	104.54	-.03	26.
PA30	-.24	104.54	-.03	26.
PA31	1.61	104.54	.20	26.
PA32	1.61	104.54	.20	26.
DKB1	1.61	104.54	.20	26.

Figure 6. Kalankuttiya BC (Reach 1: All DCs half open).

Figure 6. Kalankuttiya BC (Reach 1: All DCs half open).

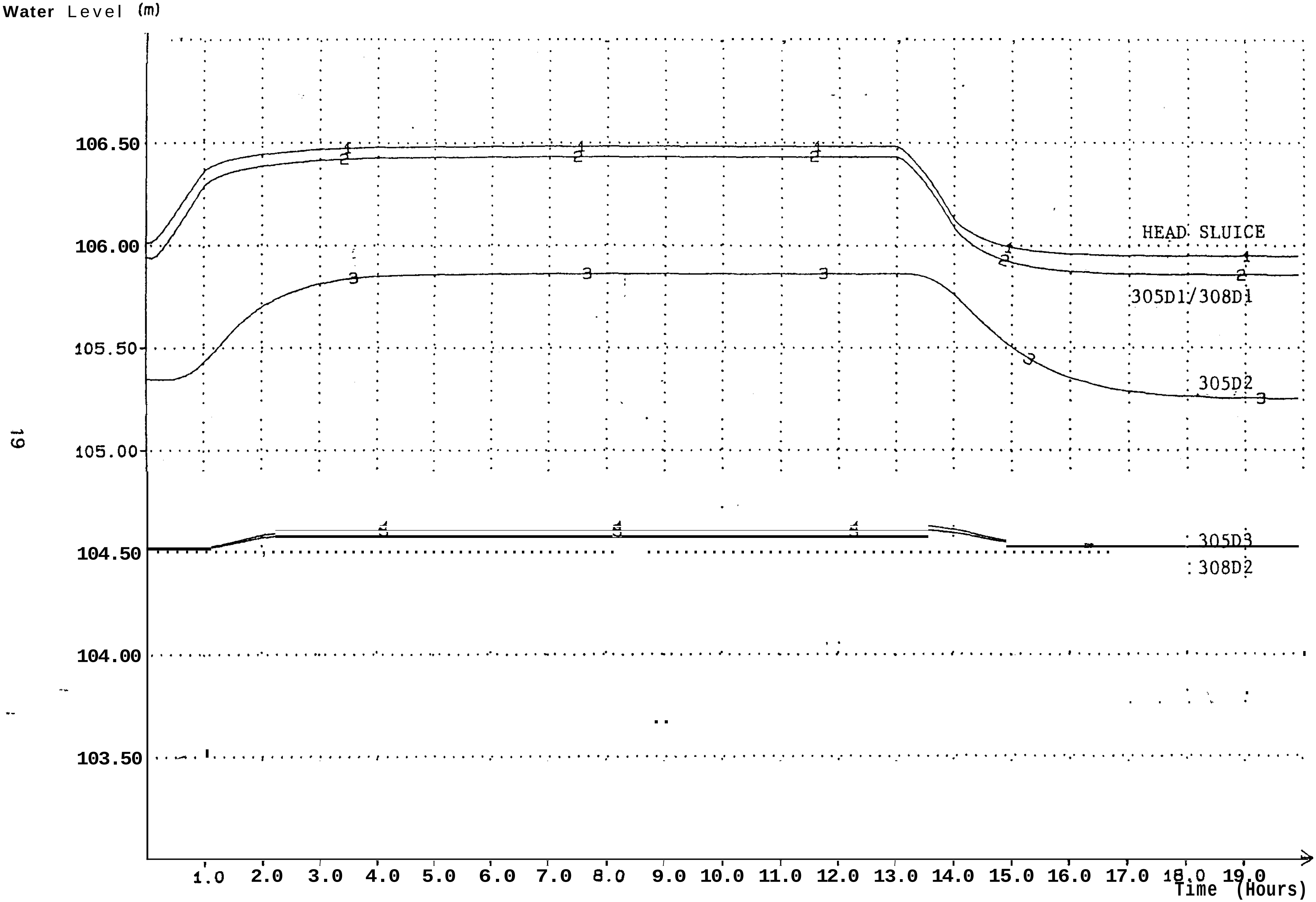


Figure 7. Kalankuttiya BC (Reach 1: All DCs half open).

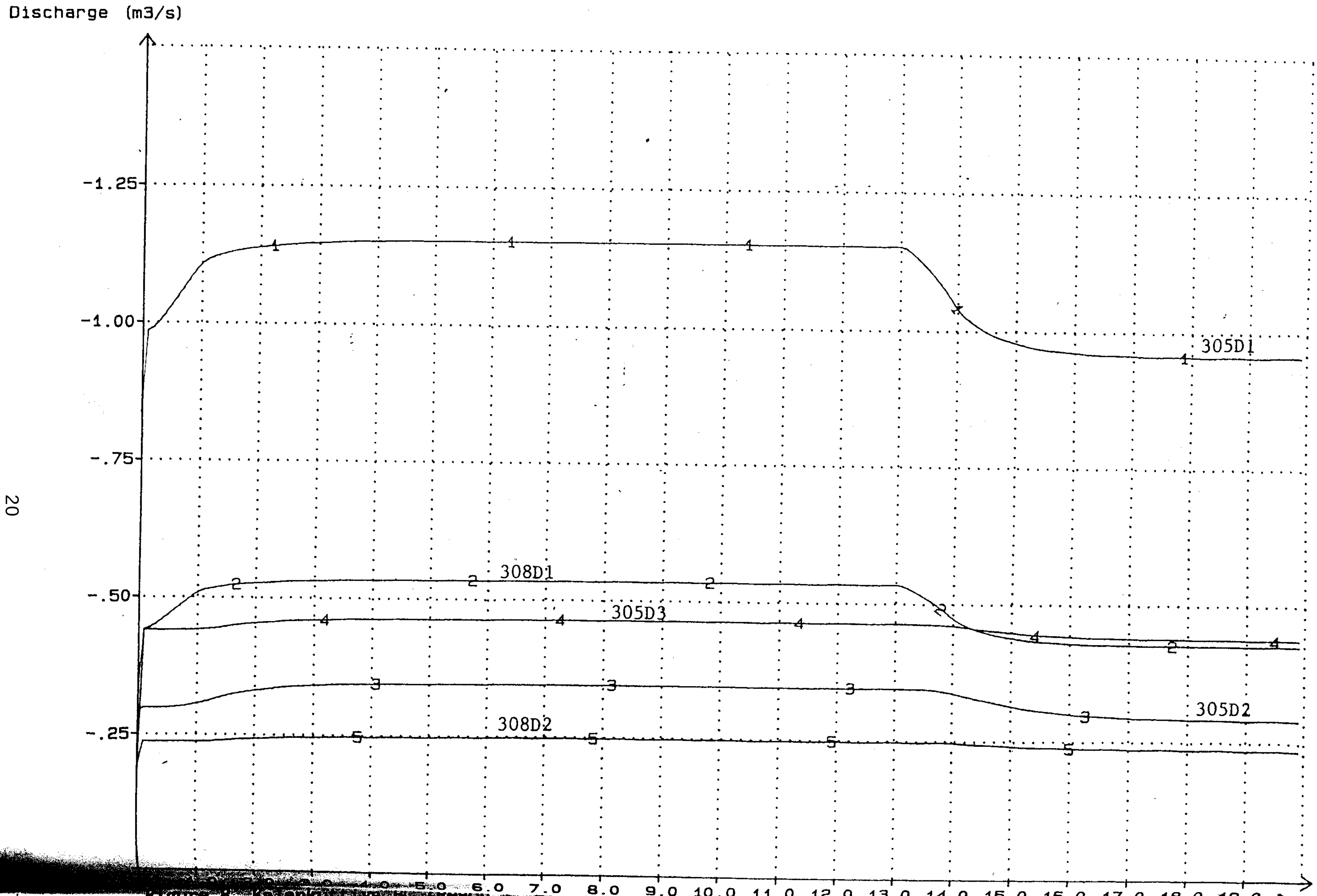


Figure 8. Kalankuttiya BC (Reach 1. All

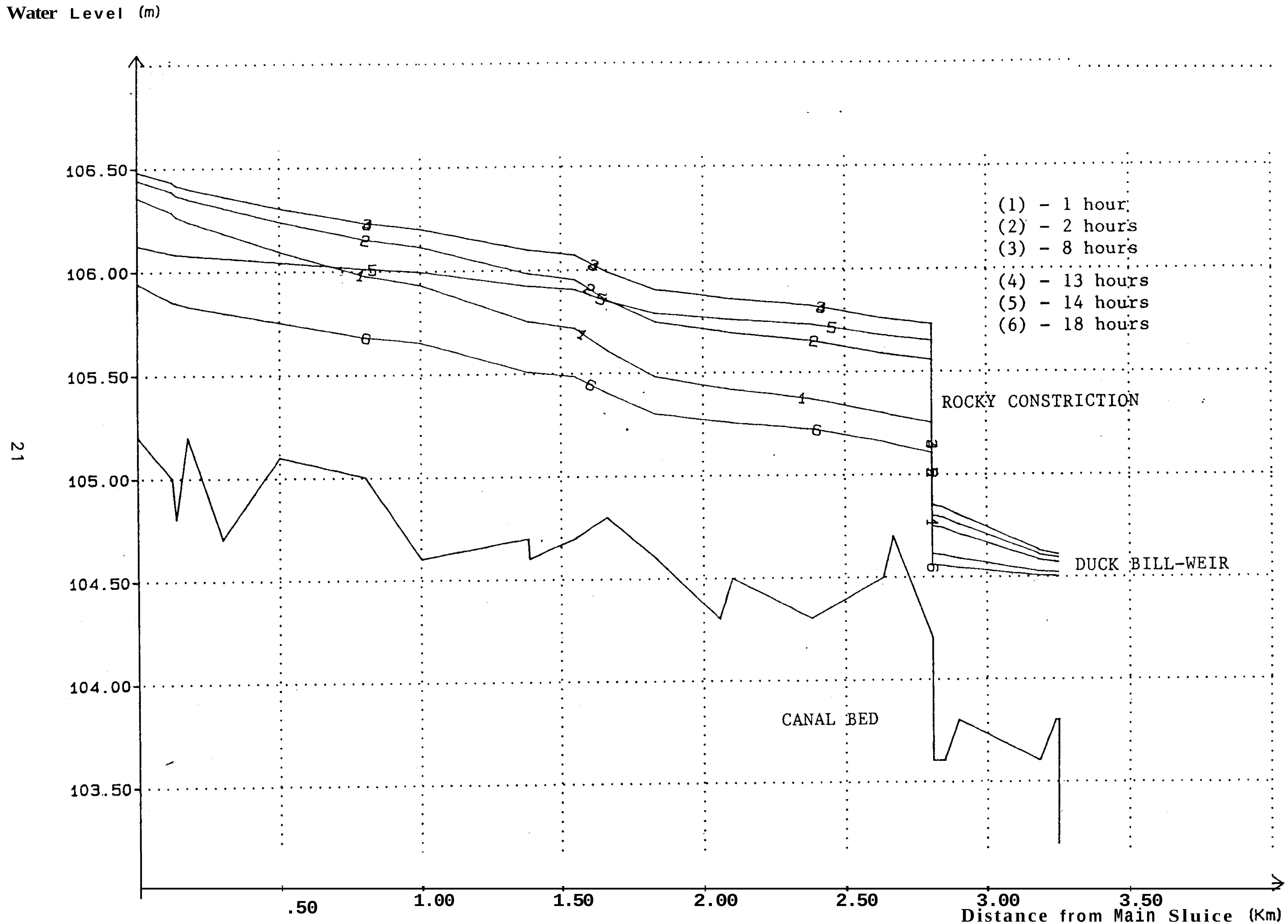
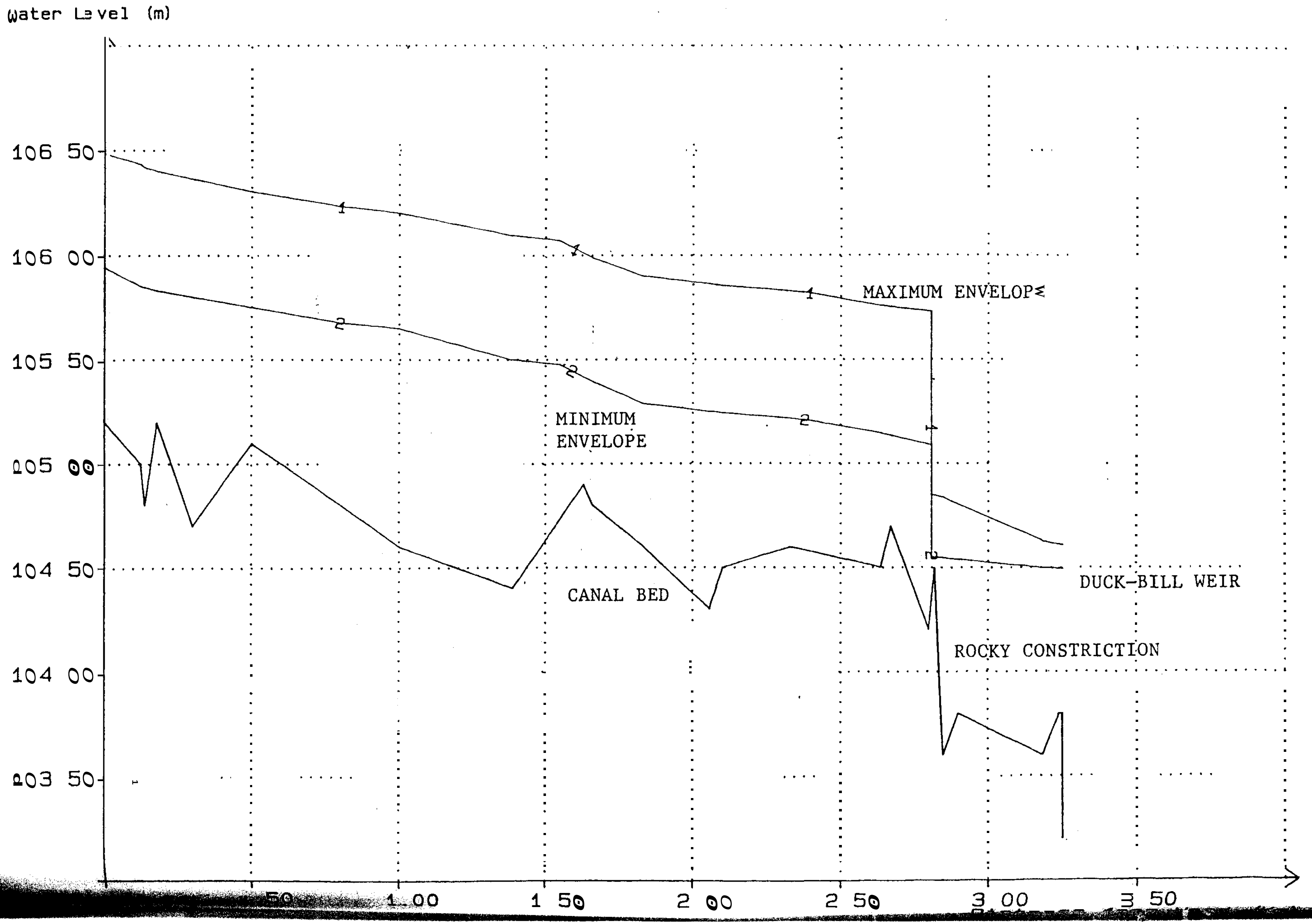


Figure 9. Kalankuttiya BC (Reach 1) - Min. Max. Envelope



305D1 (see Figure 6), the resulting change in its discharge is much less (nearly half) than that occurring .in 305D1. This is because the offtake of 305D1 consists of two pipes of 60 cm diameter each, and is capable of accommodating a major portion of the increased discharge in the branch canal, whereas the 308D1 offtake consists of only a single 60 cm diameter pipe. The smallest change in discharge is recorded by distributary canal 308D2 (closest to the duckbill weir), followed by 305D3 and 305D2. The absolute discharge in 305D3 is greater than that in 308D2, though both offtakes are subject to the same head, (see Figure 6) because 305D3 has a 60 cm diameter offtake while the 308D2 offtake is of 45 cm diameter.

These observations bring to light a danger that one should *guard* against when operating the Kalankuttiya branch canal. That is, the two uppermost canals have the capacity to extract a relatively 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 8 shows the 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 duckbill weir. Another interesting feature that comes to light is the head loss (as much as 60-80 cm) that occurs due to the rocky constriction. The effect of enlarging this section on flow propagation can easily be simulated. (This is done in Part II).

The water level envelopes of Figure 9 show the maximum and minimum levels attained in the branch canal in the course of the simulated manipulation. Comparison of the maximum envelope with the level of the canal embankment will indicate whether the canal banks are liable to overtopping as a result of this intervention. The discharge capacity of the branch canal, all the offtake gates in the first reach being half open, could be assessed. See also Cases 3 and 4 of Figure 8.

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

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, and 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 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 modification 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 distributary 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 duckbill weirs to attenuate fluctuations in hydraulic head at distributary offtakes arising from fluctuations in branch canal discharges can be easily demonstrated; discharges into distributary 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 distributary canal with a calibrated distributor (or "module");

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.; and

6. 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.

PART II

APPLICATION OF MISTRAL-SIMUTRA TO THE KALANKUTTIYA BRANCH CANAL (MAHAWELI SYSTEM H), SRI LANKA.

INTRODUCTION

It has been shown (in Part I of this Working Paper) that mathematical modeling represents a viable alternative to direct field experimentation for carrying out research to identify innovative design and management options of main irrigation canals. With the decreasing cost of computers and their increased power, investigating canal operations via mathematical simulation becomes affordable for moderately sized irrigation canals even though computer programs to do it are still to be disseminated more widely.

The use of a mathematical model does not however entirely absolve the researcher from carrying out field investigations. In particular, there is the need for:

1. a detailed field study to characterize both the topography and the hydraulics of the canal and its structures. In itself, the collection of these data is an important step towards understanding the system behavior; and

2. a calibration of the model to ensure that the model predictions match field observations of the real system with a reasonable degree of accuracy. This is especially important if the model is to be used for operational purposes. This step will ensure consistency of the data used and permit the evaluation of aggregated model parameters such as canal roughness coefficients. This process can also be highly productive in terms of generating knowledge on the system. In practice, calibration difficulties often permit to pinpoint features that are significant for the hydraulics of the canal but which might have been missed, hence calling for additional field investigation localized in that particular area.

SCOPE AND OBJECTIVES OF THE STUDY

This study forms part of IIMI's efforts to demonstrate the use of, mathematical modeling as a 'research tool to investigate the interactions between design and management of main irrigation canals with a view to identifying effective and responsive strategies for canal operation.

IIMI was afforded the opportunity, late in 1987, of obtaining a set of computer programs (MISTRAL-SIMUTRA) owned by the consulting engineering firm SOGREAH (Societe Grenobloise d'Etudes et d'Applications Hydrauliques, France), and developed some years ago mainly for carrying out studies on natural water courses. MISTRAL-SIMUTRA is a flaw simulation software package capable of imitating a given canal for which the topography, description of structures, condition of canal, etc., are known or could be established. The description of the program, its capabilities and limitations are presented in Part I of this Working Paper.

The application of MISTRAL-SIMUTRA to the Kalankuttiya Branch Canal is IIMI's first attempt to use a mathematical model for investigations on canal operations and irrigation management. This study is intended to complement the intensive field research undertaken by IIMI on the subject of Irrigation Management for Diversified Cropping at the Kalankuttiya subsystem since 1985.

The primary objective of the present study is to examine the behavior of the Kalankuttiya branch canal with a view to evaluating, through the model, the impact of the particular design of the branch canal and its regulating structures on the control of water levels along the various reaches of the canal, and hence on the primary distribution of water.

It is also expected that, with proper calibration, the model can contribute to identifying timely interventions on the system (main sluice and off-takes) to manage efficiently the weekly rotation of water issues and closures of the branch canal that is the current operational practice of the irrigation agency. (For example, ensuring equitable distribution of water during the changes while minimizing excess or shortage of water at the tail end.)

This paper presents *some* preliminary results achieved in respect of the first objective stated above. These are compared with observations made in the field during yala[2] 1987, and consequences for the operation of the system are highlighted.

BRIEF DESCRIPTION OF THE KALANKUTTIYA BRANCH CANAL

The Kalankuttiya subsystem forms part of System H of the main Mahaweli system, in the North Central Province (NCP) of Sri Lanka. The 1.86 x 10^6 m^3 Kalankuttiya Tank at the head of this subsystem commands an irrigable area of 2023 hectares (ha). The tank's own catchment area is only 26 km^2 but its water resources are being supplemented since 1977 by releases from the larger Kalawewa Reservoir which itself benefits from Mahaweli water diverted through the Polgolla Tunnel (Figures 10 and 11).

The conveyance and distribution system is made up of a 10.9 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 distributary canals, which in turn feed a network of field canals (Figure 12). In this paper the distributary canals are identified by the number of the irrigation block (e.g., 305, 306) followed by the number of the distributary itself. Thus 30905 refers to distributary canal D5 of block 309.

Each distributary canal (DC) is fed by a gated pipe outlet of 30-75 cm (12-30 inches) diameter, depending on the command area irrigated by that canal. Each field canal (FC) irrigates 6-25 farm allotments of 1 ha through a 15-cm (6-inch) 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. The soil types in the command area

Figure 10. Location map of Mahaweli Systems.

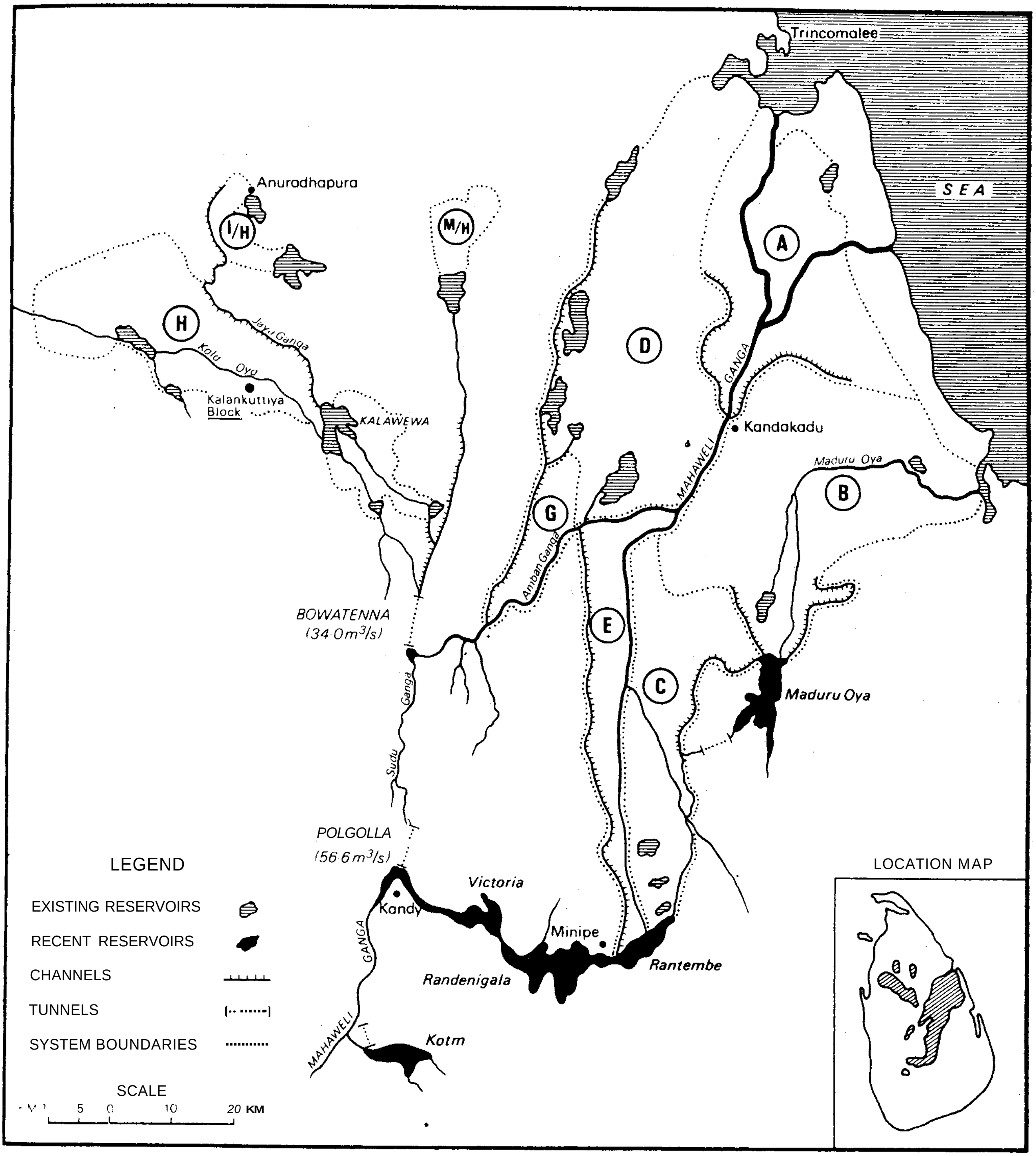


Figure 11. Kalankuttiya Block of Mahaweli System H.

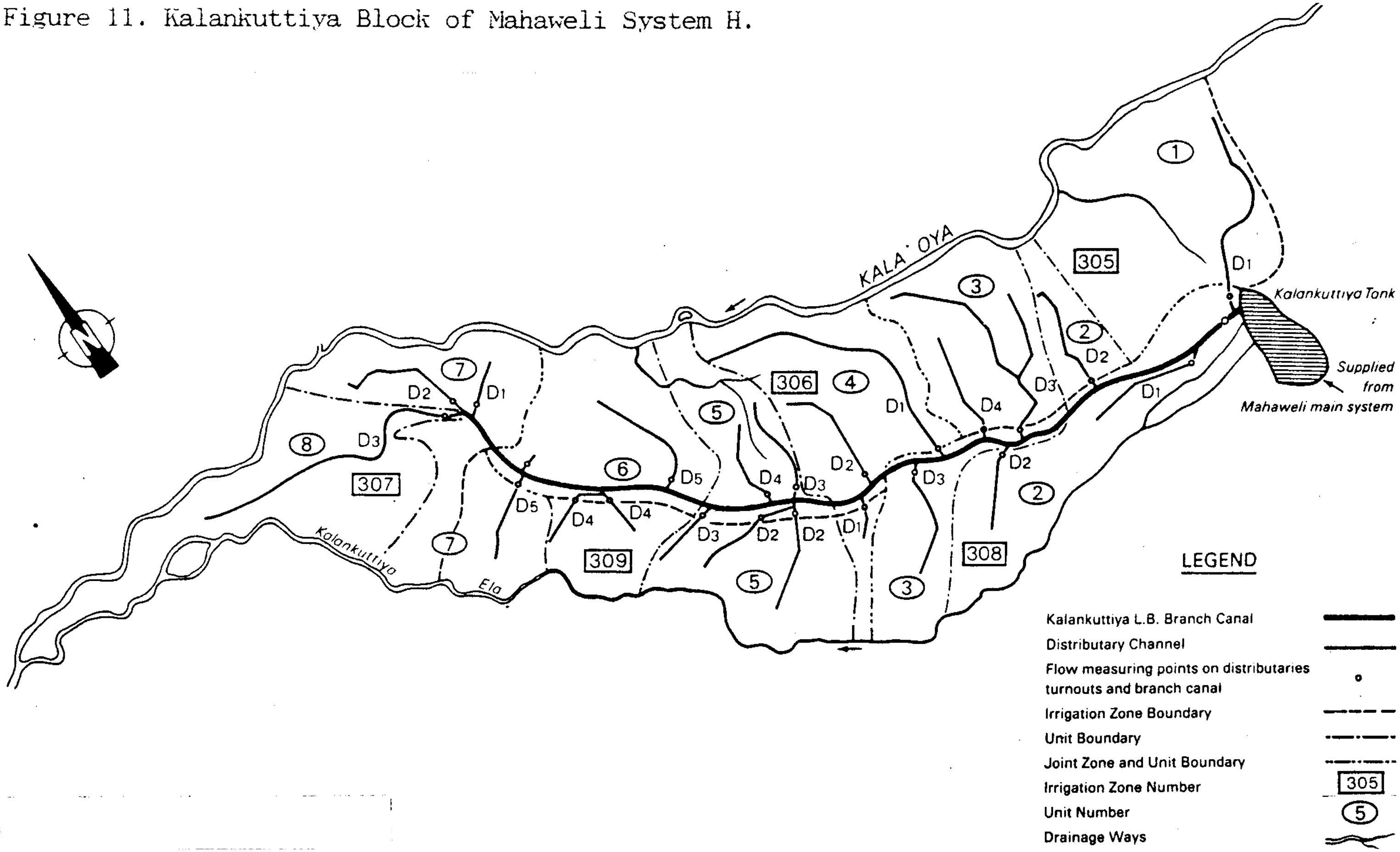


Figure 12. **Issue tree** diagram - Kalankuttiya (2023 ha).

range from well-drained Reddish Brown Earths (RBE), usually present in the upper reaches, to poorly drained Low Humic Gleys (LHG) occurring in the valley, and bottom-lands. The mid-slopes are made up of imperfectly drained soils.

Nine regulating weirs (duckbill weirs) constructed along the branch canal represent an original characteristic in the design of the canal. These fixed structures are intended to maintain hydraulic head at the distributary canal offtakes nearby, irrespective of discharge variation in the branch canal. Control of discharges into many of the distributary canals is thereby enhanced.

The management of the Kalankuttiya subsystem is vested in the Mahaweli Economic Agency (MEA). A detailed description of the MEA management structure, with special emphasis on Kalankuttiya, will be found in Raby and Merrey (1988)[3].

APPLICATION OF MISTRAL-SIMUTRA TO THE KALANKUTTIYA BRANCH CANAL

The application of MISTRAL-SIMUTRA carried out actually represents the last phase of the general procedure for building a computer model outlined in Part I of this paper. This includes the collection of relevant data to characterize the system studied and to permit its calibration. A schematic diagram of all calculation points used for the model is given in Appendix A (Figure A1).

Data Collected Initially to Create the Model

The data collected included the following:

1. Topographical survey of the canal. Cross-sections of the canal at approximately every 50 meters. Reduced levels were obtained in relation to a datum located at the head of the canal.

2. Locations and descriptions of all hydraulic structures and offtakes. This includes the levels of the crest of the duckbill weirs, pipe invert levels and pipe diameters of the offtakes and spindle length of each of the offtakes at full closure. Most of this information was obtained by commissioning a surveyor for the purpose during the period of closure of the canal between yala 1987 and maha 87/88.

3. Head-discharge relationships at the lateral offtakes for different gate settings. Since these were not directly available (e.g., in the form of rating curves), theoretical equations were used instead, taking into account the area of opening of the gate corresponding to different settings.

4. Head-discharge relationships of the duckbill weirs. Here too theoretical equations were used, taking into account the total length of the weirs.

5. Downstream boundary condition. A head-discharge relationship at the tail of the branch canal has been derived from observations available at this location relating discharge passing through distributary 307D3, that also serves as a drainage channel, and levels recorded in the branch canal.

Data Collected in View of the Model Calibration

Once the basic data used to describe the topography of the canal and the hydraulics of its structures have been entered, the model has to be calibrated so that it accurately reflects actual field conditions. This is primarily a field exercise in which water surface elevation in the canal has to be measured together with the corresponding flows so that it can be matched tentatively with the water surface profile computed by the model for the same 'flow conditions.

At Kalankuttiya, two campaigns of observations for calibrating the model have been carried out (on 3 and 11 August 1988) at a time when the flow in the branch canal was supposed to be steady. Discharges in the various reaches of the branch canal were estimated through current metering and water levels in the canal 'were determined by means of staff gauges placed at a number of locations of interest for the model calibration. Simultaneously, at each open offtake, the spindle length, staff gauge reading in the main canal, and the hump gauge reading in the weir box at the head of each distributary canal were noted to assess the flow diverted into each of these canals.

Doing this efficiently requires keeping track of a number of gauge readings that have been systematically converted to reduced levels to permit hydraulic computations and estimates of lateral flows. Flows can be estimated by using either the hump gauge rating curves, if any exist, or the differential head over the offtake gates coupled with the orifice flow equation which has so far proved to be effective and allows double checking.

Model Calibration

The parameter related to the roughness of the canal (Manning or Strickler roughness coefficient) cannot be directly measured on the field. Furthermore, it could vary from section to section of the canal depending on the type of surface of the canal bed and embankments, presence of weeds, etc.

Identifying an appropriate aggregated roughness coefficient for each of the different sections of the canal is one of the main results of the calibration of the model. Hence keeping all factors affecting flow at the same value as that observed on the field (inflow, lateral flows, etc.,) the parameters are varied until the water surface elevations computed by the model match the levels observed on the field. This is usually performed under a steady flow regime since unsteady flow measurements would require not only spatial observations but also their values in time for each observation point.

Although the above process seems straightforward it requires careful attention as there may be difficulties brought about by special features in the canal or uncertainty of some key parameters affecting flow. For instance the presence of a rocky constriction within the first reach of the Kalankuttiya Branch canal (a relatively narrow, rocky section where the flow could pass into the supercritical zone) has required specific consideration since the model cannot handle supercritical flow. Therefore an 'equivalent structure' that would exhibit similar hydraulic behavior had to be imagined and introduced at this point. This took the form of an equivalent weir whose dimensions were suitably adjusted until the model was able to reproduce the same loss of hydraulic head observed in the field.

So far, the calibration of the model has been performed for the first two reaches of the branch canal and for one particular steady regime only. The calibration process has still to be finalized for the rest of the canal using the data that have already been collected for steady state conditions and also, if possible, data that will be collected for unsteady flow Conditions. Such conditions would be generated by a calibrated release of water at the main sluice while maintaining the rest of the system untouched till the end of the experiment. The propagation along the canal and diffusion of the wave generated by such a release will be monitored.

A Strickler coefficient of 30 (Manning's n = 0.033) has been found adequate for the calibration of the first reach together with the equivalent weir structure that substitutes for the rocky section. The calibration of the second reach is still perfectible. Discrepancies between the observed and model predicted water levels immediately upstream of 305D4 cannot be reduced unless the value of the roughness coefficient is taken out of an acceptable range. It would thus be necessary to conduct further localized investigation on the field to determine the likely cause of this difference (perhaps a minor constriction) and to take appropriate measures to adjust the model. Figure 13 presents the results of the current calibration of the first two reaches of the canal; the water surface computed by the model is compared with the levels actually observed at some points. The Strickler value adopted for the second reach in this computation is 23, subject to the verification mentioned above.

Pending the calibration of the entire model, a Strickler coefficient of 25 (Manning's n = 0.040) has been assumed for the rest of the canal, which appears to be reasonable, considering that these sections are overgrown with weeds.

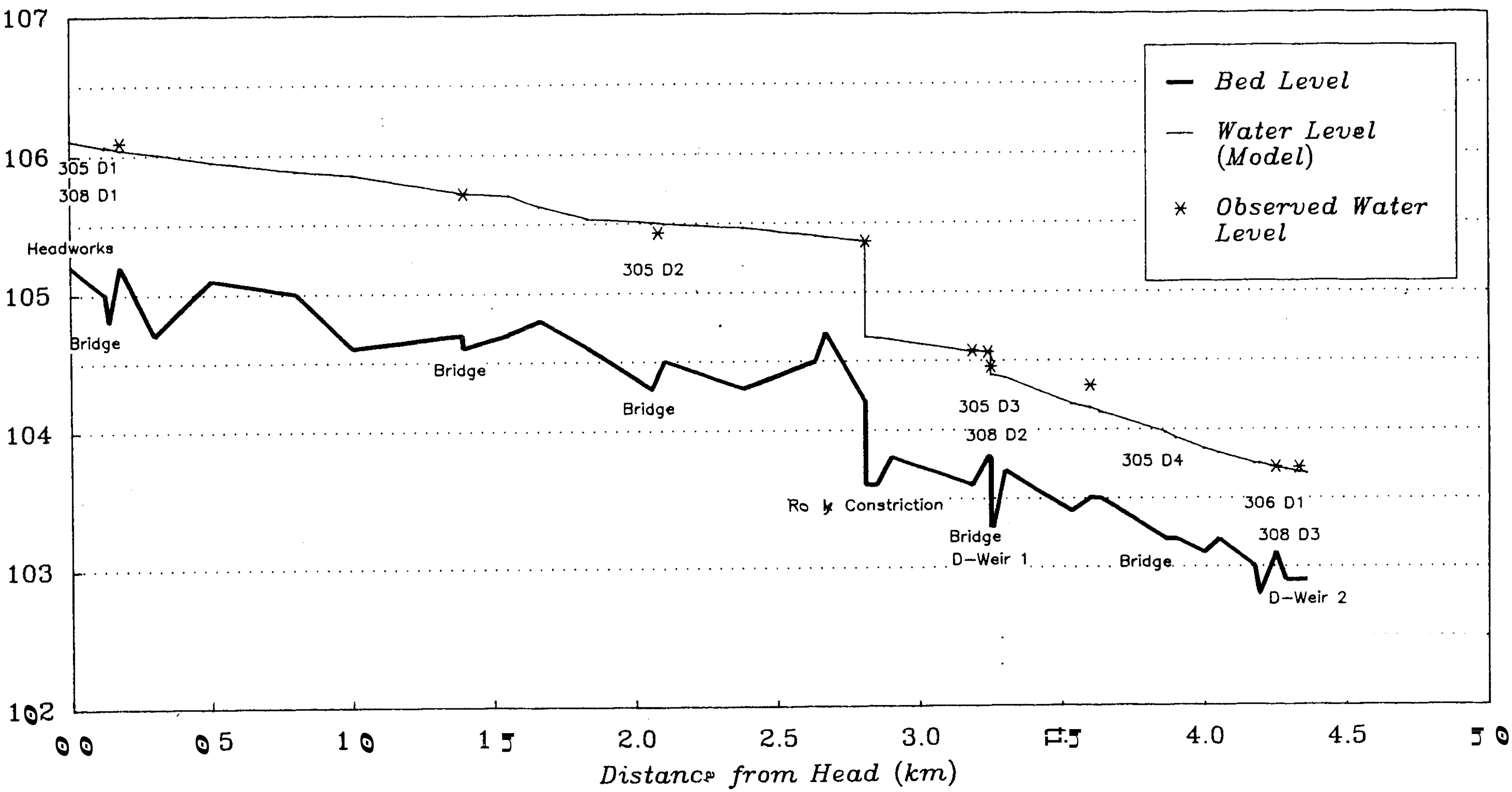
SIMULATIONS PERFORMED THROUGH THE MODEL

Current Operational Practices of the Canal

Allocation of water to each distributary canal depends on the extent irrigated in the command area of each DC. It has been a common practice to implement rotational water issues among the distributaries. The water flow in the branch canal is also regulated accordingly by adjusting the main sluice at its head. However, the rotational pattern is not unique. It varies from season to season and even within a given season.

Figure 13. Kalankuttiya Branch Channel

Calibration of MISTRAL (03 *August* 1988)



For example during yala 1988, the water issues to the distributary canals have followed a 7-day rotation; water was issued simultaneously to all 20 distributary canals for the first 3 days and they remained closed for the next 4 days. The main sluice at the head of the branch canal also remained shut during this latter period.

On the other hand the previous season (maha 1987/88) also commenced with a 7-day rotation although the pattern of water issues was different. The upper 12 DCs were issued with water for the first 4 days of a rotation, whilst only the lower 8 DCs received water for the next 3 days. Midway through the season the rotational pattern was altered whereby all DCs except the first two (i.e., 305D1 and 308D1) were supplied during the first 3 days, all 20 DCs received water on the fourth day, and only the first 2 DCs remained open over the last 3 days (this is similar to the rotational pattern practiced in yala 1987). The rotational period was extended to 9, 10 and even 12 days during the latter part of the season due to inadequacy of water.

In maha 1986/87, 8-day rotations were practiced throughout the season; the first 9 DCs were supplied during 4 days followed by the remaining 11 DCs over the next 4 days.

It is thus seen that the agency is experimenting with different operational modes every season. The choice of a particular mode is probably dictated by the availability of water resources at Kalawewa and the reliability and predictability of releases from Kalawewa to replenish the Kalankuttiya Tank.

Scenarios Simulated and Assumptions

The operation of the branch canal has been simulated under water supply/demand assumptions that could correspond to maha with a total irrigated area of 2,021 ha but for two different modes of delivery: either simultaneous delivery to all DCs, or supplying DCs in the upper and lower sections of the branch canal alternately in order to reduce the maximum flow to be issued in the canal.

For the simulation, the DC water issues have been computed on the basis of a uniform water requirement of 2.5 inches (63.5 mm) per week plus 10 percent conveyance losses in each DC. The weekly water requirement is supposed to be delivered over a period of 3 days. Actually, MEA would issue water over a period of 4 days, especially because all 20 DCs are to be supplied simultaneously with their maha season requirements. Therefore, the 3-day water issue assumed for the simulation is a very severe constraint put on the system. This simulation in effect permits to assess the behavior of the canal under an extreme maximum flow of 5.92 m^3/s (209 cusecs) at the headworks, something which might not be practicable in reality.

Table 2 indicates the discharge requirements of each distributary canal resulting from the above computations and assuming seepage losses in the branch canal at the rate of 43 liters/s/km length of canal.

Table 2. Theoretical water issues as estirated *for* total cultivation under Kalankuttiya tank.

Canal no,	istance fror head (km)	Seepage oss (DC) (m3/s)a	ormand area (ha.)	Water equirement (m3)	later issue (m3/s)b		eqd.rair canal flow (m3/s)	ater issue (m3/s)	
					neglect seepage	with seepage		otn. in op sec.	otn. in ow sec.
305 D1	0.123	0.005	309	196,215	0.833	0.838	5.916	0.838	0.005
308 DI	0.123	0.000	71	45,085	0.191	0.191	5.078	0.191	0.000
305 D2	2.056	0.083	77	48,895	0.208	0.291	4.886	Q.291	0.083
305 D3	3.179	0.048	104	66,040	0.280	0.329	4.596	0.329	0.048
308 D2	3.239	0.003	69	43,815	0.186	0.189	4.267	0.189	0.003
305 D4	3.635	0.017	71	45,085	0.191	0.208	4.079	0.208	0.017
306 D1	4,193	0.024	a4	53,340	0.226	0.250	3.870	0.250	0.024
308 D3	4.331	0.006	104	66,040	0.280	0.286	3.620	0.286	0.006
306 D2	4.585	0.011	104	66,040	0.280	0.291	3.334	0.291	0.011
309 D1	5.341	0.033	59	37,465	0.159	0.192	3.043	0	0.192
306 D3	6.085	0.032	33	20,955	0.089	0.121	2.851	0	0.121
309 D2	6.150	0.003	74	46,990	0.199	0.202	2.730	0	0.202
306 D4	6.500	0.015	49	31,115	0.132	0.147	2.528	0	0.147
309 D3	6.500	0.000	103	65,405	0.278	0.278	2.381	0	0.278
306 D5	8.340	0.079	172	109,220	0.464	0.543	2.103	0	0.543
309 D4	8.734	0.017	93	59,055	0.251	0.268	1,561	0	0.268
309 D5	9.860	0.048	84	53,340	0.226	0.275	1.293	0	0.275
307 D1	10.563	0.030	68	43,180	0.183	0.213	1.018	0	0.213
307 D2	10.920	0.000	71	45,085	0.191	0.191	0.805	0	0.191
307 D3	10.920	0.015	222	140,970	0.598	0.614	0.614	0	0.614
TOTAL		0.470	2021	1,283,335	5.446	5.916		2.873	3.240

a Seepage loss = 43 l/s/km and is accounted for in every DC.

b A water requirement of 2.5 inches to be supplied during a period of 3 days with 10% losses in the DCs is assumed.

To assess the magnitude of the range of the level variations in the branch canal between minimum and maximum flow, a simulation for a minimum flow of 0.47 m^3/s (17 cusecs) at the main sluice was also performed using the same seepage rate. This flow is the minimum that would permit to keep the water flowing all along the branch canal assuming that all offtakes are closed.

Thus a total of four scenarios have been simulated as follows:

Case 1: Flow at Main Sluice = 0.47 m^3/s (17 cusecs); all distributary canals are closed except the last (307 D3) which also serves as a drainage channel;

Case 2: Flow at Main Sluice = 5.92 m^3/s (209 cusecs); all distributary canals are open for maximum irrigation delivery in the maha season (assuming entire command area is cultivated);

Case 3: Flow at Main Sluice = 2.87 m^3/s (101 cusecs); the 9 distributary canals (i.e., 305D1-306D2) in the 3 upstream reaches are open for maximum irrigation delivery in the maha *season* (assuming entire command area is cultivated);

Case 4: Flow at Main Sluice = 3.24 m^3/s (114 cusecs); the 11 distributary canals (i.e., 309D1 to 307D3) in reaches 4-10 are open for maximum irrigation delivery in the maha season (assuming entire command area is cultivated);

In each *case*, the water surface profile corresponding to the steady-state regimes that would be established in the various reaches of the Kalankuttiya branch canal have been computed. Graphic outputs are given in Appendix A (Figures A2-A8).

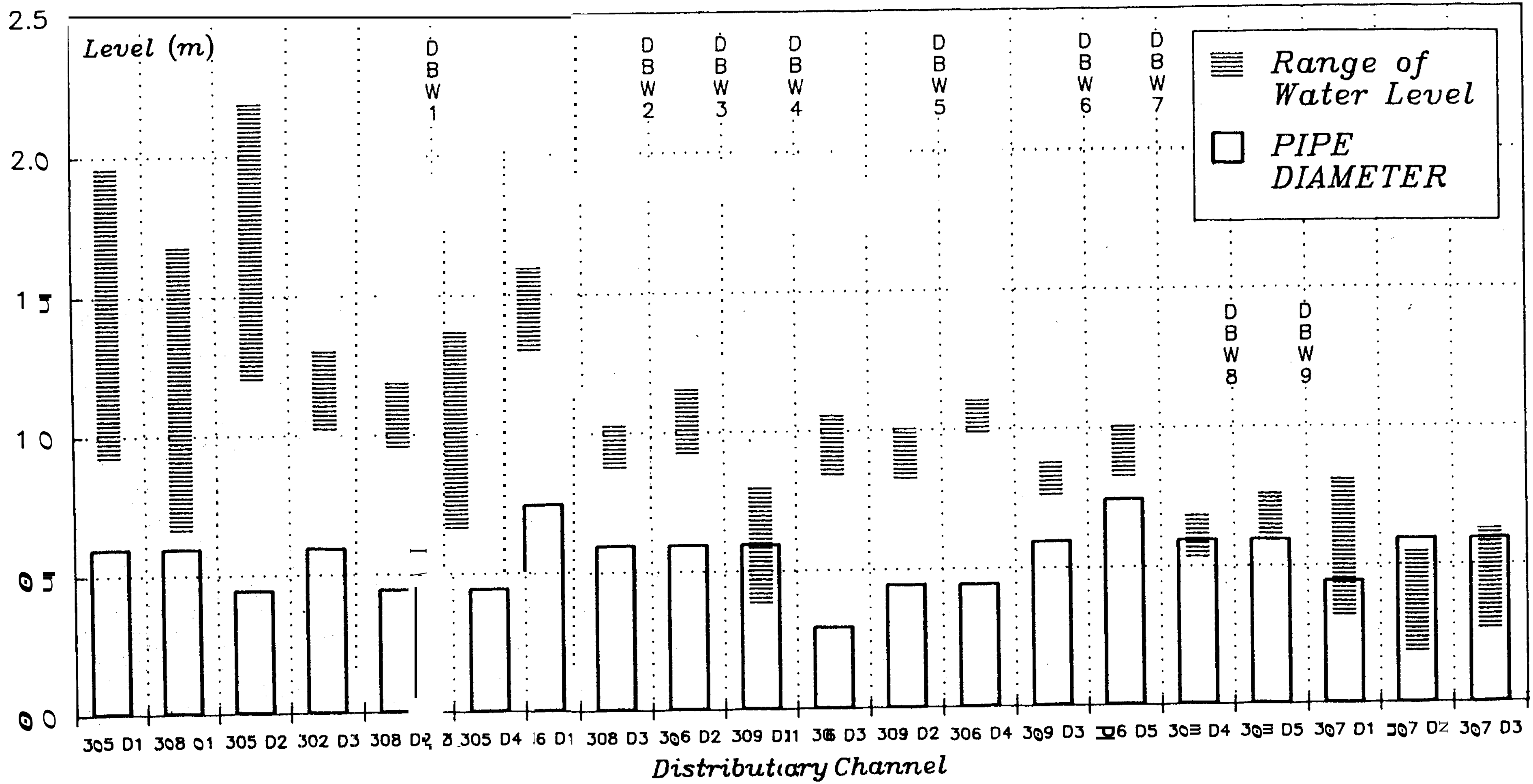
Table B1 (Appendix B) indicates the complete set of results generated by the model in terms of the flow parameters (water level, discharge and velocity) at each computational point for *each* of the scenarios simulated. In this table, negative discharge indicates flow out of the branch canal (e.g., into DCs), or aggregated seepage losses (Case 1).

DISCUSSION OF RESULTS

1. The analysis of the outputs of the simulations performed shows that the range between minimum and maximum water levels as predicted by the model (Case 1 and Case 2, respectively) varies substantially along the branch canal (Figures A2-A8). The magnitude of this range fluctuates from about 10 centimeters to more than 1 meter, depending upon the distance to the downstream weir, if any (Figure 14). This illustrates the obvious regulating effect of the duckbill weirs (DBW) on the control of water levels upstream of themselves irrespective of the variations of flow in the branch canal. But it also indicates the limits of the regulating effect that can be achieved by this means. Maximum impact in terms of level control is obtained in the immediate vicinity of the

Figure 14. Kalankuttiya Branch Channel

Maximum Expected Range of Water Level above Pipe Invert Level



duckbill weirs. The regulating effect soon disappears with distance. For instance, at the offtake to distributary 305D4 which is located 700 meters upstream of DBW no.2, the expected range of water level fluctuation is about 50 cm between maximum flow (4 m^3/s) and minimum flow (0.3 m^3/s) at this location. On the other hand, at the offtake to distributary 308D3, which is located immediately upstream of DBW no.2, the expected range is only 16 cm.

2. The offtakes located at both extremes of the branch canal do not benefit from any form of regulation. Water levels at both locations would fluctuate in a range of 50 cm to 1 meter when the branch canal flow varies between the maximum and minimum values considered for the simulations.

3. The first three DCs at the head of the branch canal are located too far upstream of the first duckbill weir to benefit from its regulating effect. Moreover, the rocky constriction existing in that reach seems to contribute to further increasing the range of level variations. Also, since the canal is very narrow in this section a relatively large head variation is observed even for a small variation in discharge. This characteristic effectively defeats the purpose of the duckbill weir located 400 meters downstream.

   To assess better the impact of the rocky constriction on the regulation and potential improvement that would result from its widening, simulations corresponding to Case 1 and Case 2 were repeated after removal of this bottleneck. The results are shown in Figures A9 and A10 in Appendix A. The impact of the removal is greatest at the offtake to distributary 305D2; the range of water level variation at this point could be expected to be reduced by nearly 50 percent by enlarging the branch canal and smoothing the canal bed level in that area. Although discharge control into this distributary would thereby be considerably enhanced, the economic competitiveness of this physical intervention on the branch canal against other flow control options will have to be examined.

4. In the tail-end reach, the range of predicted water level variations is influenced by the downstream boundary condition imposed in the model. The condition adopted in all our simulations was a head-discharge relationship defined with the support of field observations. As a result, it appears that for a discharge of about 1 m^3/s at the tail, which corresponds to the simulation at maximum flow, the last duckbill weir (DBW no.9) would be submerged, in which case the weir would no longer control effectively the level at the offtake to 309D5. Also, it should be noted that at the tail, 307D3, which also serves as the drainage outlet of the branch canal, is frequently obstructed by debris. The consequence of this is that water levels in that reach are temporarily raised with eventual flooding of the area until the obstruction is removed. Thus the actual range of level variation at the last three offtakes at the tail is likely to be greater than that predicted by the model.

5. bother result which is apparent from Figure 14 is that the water level variations in the branch canal represent different operating heads with respect to the pipe inverts at the offtakes. Besides the magnitude of the range of variation itself, another parameter to be considered is the hydraulic head over the pipe invert level of each offtake. The ratio between these two parameters is significant when comparing the conditions under which the different offtakes operate. Figure 14 suggests that these conditions are very different from one offtake to another, even amongst those that benefit from level control by means of the duckbill weirs. This has implications for canal operations and the management of the system since a high operating head above the pipe invert with a limited range of variation of water level would require less gate operations for control of the discharge diverted into the corresponding distributary. In general, the outlets on the Kalankuttiya branch canal appear to be placed in such a way that the water depth above the pipe invert levels is maintained at around 60 cm for the lowest flow. But this does not seem to be the case for 309D1, 309D4, and the three tail-end distributaries (307D1, 307D2, 307D3). This would render diversions at these offtakes more sensitive to the variations of level (and hence discharge) in the branch canal than other similarly located offtakes. It is worthwhile to highlight the fact that although 309D1 and 309D4 are located relatively close to duckbill weirs, hence well-regulated in terms of level control, they would still be subject to variations in discharge unless frequent offtake gate adjustments are made.

Table 3 (which is extracted from Table B1) regroups the model results in respect of computational points corresponding to the offtakes and structures on the branch canal. Table 3 also indicates the values of the ratio mentioned above, computed at each distributary canal offtake as follows:

$$\frac{0.5 * (\text{maximum head - minimum head})}{\text{mean head above pipe invert level}} \quad \text{-------------(1)}$$

This facilitates comparison with actual field observations (see below) arid provides a means to compare conditions under which offtakes are operated in the branch canal, as a result of the design of the canal.

COMPARISON WITH FIELD OBSERVATIONS

In yala 1987, IIMI staff4 began to gather information with the express intention of investigating the operations of the Kalankuttiya branch canal and its performance from the point of view of the water distribution from the branch canal and its manageability. The original design features of the canal made such a case study particularly interesting.

During that season a series of observations of the branch canal water levels at various stations along the canal was recorded from July 198i to September 1987 and statistical analysis of these observations was performed. In particular, the frequency histograms of water levels in class intervals of 5 cm, and'the corresponding cumulative distribution functions were determined at a number of offtakes (305D1, 305D2, 305D3, 305D4, 308D2, 308D3, 306D1, 307D1 and 307D2).

For comparison purposes with the results obtained with the model, the interquartile range (i.e., $H_{0.75} - H_{0.25}$) of the distribution of the observed water levels, and the median ($H_{0.50}$) were computed with respect to the pipe invert level of the corresponding offtake. The following ratio was also computed:

$$\frac{\text{Interquartile range of levels}}{\text{Median depth above offtake invert}} \quad \text{-------------} \quad (2)$$

The results in respect of the above offtakes are shown in Table 4.

Several conclusions emerge from the comparison of the field observations against the model predictions.

1. The magnitude of the dispersion in water levels observed in the branch canal is matched by the magnitude of the range of level variations predicted by the model between minimum and maximum flows. This is illustrated in Figures 15, 16, and 17, which represent the distribution of branch canal water depths at 305D1, 305D2 and 305D3, respectively, along with the range of water levels predicted by the model for the different flow regimes. This gives clear evidence of the effective level control performed by the duckbill weir (DBW no.1) in the case of 305D3 as opposed to the relatively unregulated situations of 305D2 and 305D1.

2. The water depths predicted by the model generally tally rather well with the levels observed in the canal. Most of the observations correspond to the lower portion of the predicted range, but this is because the flows in the canal during the period of observation were rather low compared to the maximum flow for which the simulation was performed (Case 2). During the period of observations, the issues at the main sluice were in the range of 0.5 m^3/s to 2.7 m^3/s with an interquartile range between 1 m^3/s and 2.2 m^3/s. However, it must be borne in mind that model predictions match the field observations best in the first reach, which is actually the only reach that has been calibrated so far. As far as 305D1 is concerned, the processing of observed water levels has been performed separately -- a) for the total period of observations, and b) only for the periods of water issue to this canal -- because this distributary was supplied individually during yala 1987 with limited flow in the branch canal. The distribution of branch canal levels observed during the periods of issue to this particular canal reflects this situation; most of the observed levels are below the minimum level predicted by the model (Figure 15). This is because the observation station in the branch canal is located downstream of the 305D1 offtake and the flow in the branch canal at this point, after supplying the requirements of 305D1, would have been less than the minimum value (0.47 m^3/s) adopted in the simulations.

3. The ratios defined above for both the model predictions and the field observations (equations 1 and 2) have been compared in Figure 18. It

shows that similar conclusions can be reached, either through direct field observations or by simulations through the model, regarding the comparative assessment of the design-related conditions affecting the delivery of discharge at each individual offtake in terms of level control in the parent canal.

CONCLUSIONS

The insight gained by IIMI on the Kalankuttiya branch canal through its first application of mathematical modeling in Sri Lanka is promising. With limited resources, and though the model is still not completely calibrated, the application has already highlighted peculiarities in the design of this canal that have consequences for its operations and are likely contributory factors to its performances. So far, the model has been useful to IIMI as a research tool towards getting a holistic view about the operations of the branch canal. It will also help to focus future field observations specifically on aspects revealed by the model and which might have otherwise been overlooked. By no means could the model substitute for fieldwork, but on the contrary modeling would contribute to make the fieldwork more insightful and more efficient. The application should thus continue up to the point of performing unsteady flow simulations that will provide further information of particular interest to the Mahaweli Economic Agency and ultimately lead to identifying the most effective way to operate the Kalankuttiya branch canal under particular sets of constraints.

NOTES

1. The set of partial differential equations (Continuity equation and Dynamic equation) that governs unsteady flow in open channels.

2. The yala or *dry* season is associated with the southwest monsoon and usually takes place between April and October. Cultivation also takes place during the maha or wet season associated with the northeast monsoon.

3. Raby, Namika and Merrey, Douglas. 1988 (forthcoming). Performance control for professional management of an irrigation system: A case study from System H in Sri Lanka, IIMI Research Paper No. 6.

4. The analysis of field observations used in this paper is based on data collected by an IIMI Research Assistant; *see* also "Yala 1987: End of Season Report" by S. Pathmarajah, Draft Report, IIMI, December 1987.

REFERENCES

Chambers, Robert. 1988. Managing canal irrigation: Practical analysis from South Asia. New Delhi, India: Oxford & IBH Publishing Co.

Table 3

KALAKUTTIYA BRANCH CANAL

Results of simulation of 4 scenarios through the model.

LOCATION	Distance from Head (km)	Pipe Diam. (m)	Pipe invert Level* (m)	CASE 1 (Min. Flow) Q(DC) (m3/s)	CASE 1 (Min. Flow) Q(MC) (m3/s)	CASE 1 (Min. Flow) Water Level(m)	CASE 2 (Max. Flow) Q(DC) (m3/s)	CASE 2 (Max. Flow) Q(MC) m3/s)	CASE 2 (Max. Flow) Water Level(m)	CASE 3 (Rotn. Up) Q(DC) (m3/s)	CASE 3 (Rotn. Up) Q(MC) (m3/s)	CASE 3 (Rotn. Up) Water Level(m)	CASE 4 (Rotn. Down) Q(DC) m3/s	CASE 4 (Rotn. Down) Q(MC) m3/s)	CASE 4 (Rotn. Down) Water Level(m)	Water Level Range ΔH (m)	Mean above Invert H_m (m)	$\frac{\Delta H}{H_m}$
Headworks	0.000	NA	NA	NA	0.47	105.54	NA	5.92	106.58	NA	2.90	106.ill	NH	3.24	106.28	**1.04**	NA	NA
305 D1	**0.122**	0.60	104.59	0.00	0.47	105.50	0.84	5.92	106.55	0.84	2.90	105.95	0.00	3.24	106.25	**1.05**	**1.43**	0.366
303 **D1**	0.123	0.60	104.85	0.00	0.47	105.50	0.19	5.08	106.54	0.13	2.06	105.95	0.00	3.23	106.25	1.04	1.17	0.444
305 **D2**	2.055	0.45	103.77	0.08	0.47	104.96	0.29	4.89	105.97	0.29	1.87	105.35	***0.08***	3.23	105.73	**1.01**	1.70	0.298
ROCKY CON.	2.810	NA	NA	NA	0.38	104.77	NA	4.60	105.82	NH	1.58	105.19	NA	3.15	105.60	1.05	NA	NA
305 D3	3.178	0.60	103.44	0.05	0.38	104.46	0.33	4.60	104.75	0.33	1.58	104.52	0.05	3.15	104.62	0.29	1.16	0.124
308 **D2**	3.238	0.45	103.52	0.00	0.33	104.46	0.13	4.27	104.72	0.19	1.25	104.52	0.00	3.10	104.61	0.26	1.07	0.121
0-Weir 1	**3.250**	NA	104.45	NA	0.33	104.46	**NA**	4.08	104.72	NA	1.06	104.52	NA	3.10	104.61	0.26	NA	**NA**
305 D4	3.634	0.45	103.08	0.02	0.33	103.73	0.21	**4.08**	104.45;	0.21	1.06	103.90	0.02	3.10	104.33	0.72	1.01	0.356
306 D1	4.192	0.75	102.32	0.02	**0.31**	103.61	0.25	3.67	**103.92**	0.25	0.85	103.63	0.02	3.08	103.88	0.31	1.45	0.107
308 **D3**	4.330	0.60	102.74	0.00	0.29	103.61	0.29	3.62	103.77	0.29	***0.60***	103.61	0.00	3.06	103.76	0.16	0.95	0.084
0-Weir 2	4.358	NA	**103.59**	NA	0.28	103.61	NA	3.33	103.74	NA	0.32	103.61	NA	3.05	103.73	**0.13**	NA	NA
306 02	4.584	0.60	101.75	0.01	0.28	102.72	**0.29**	3.33	102.91	0.29	0.32	102.66	0.01	3.05	102.91	0.25	1.03	0.121
D-Weir 3	4.592	NA	102.69	NA	0.27	102. **72**	NA	3.04	102.90	NA	0.03	102.66	NA	**3.04**	102.90	**0.24**	NA	NA
309 **D1**	5.340	0.60	100.95	0.03	0.27	101.42	0.19	3.04	101.76	NH	**Nh**	NA	0.19	3.04	101.76	0.43	**0.59**	0.361
0-Weir- 4	5.509	NA	101.38	NA	0.24	101.41	NA	2.85	101.59	NA	NA	NA	NA	2.85	101.59	0.26	NA	NA
306 **03**	6.084	0.30	99.20	0.03	0.24	100.03	0.12	2.85	100.26	NA	NA	NA	0.13	**2.85**	**100.26**	0.23	0.95	0.122
309 D2	6.149	0.45	99.21	0.00	0.21	100.03	0.20	2.73	100.23	NA	NA	NA	0.20	2.73	100.23	0.20	0.92	0.109
0-Weir 5	6.174	NA	100.03	NA	0.20	100.03	NA	2.53	100.21	NA	NA	HA	NA	2.53	100.21	**0.18**	NH	**NA**
DROP ST.	6.242	NA	98.48	NA	0.20	'98.61	NA	**2.53**	99.18	NA	NA	NA	NA	**2.53**	99. 18	0.57	NH	**NA**
306 D4	6.499	0.45	96.13	0.01	0.20	97.11	0.15	2.53	97.25	Na	NA	NA	0.15	2.53	97.25	0.14	1.05	**0.067**
309 03	**6.500**	0.60	96.36	0.00	0.19	97.11	0.28	2.38	97.25	NA	NA	HA	0.28	2.38	97.25	0.14	0.92	0.085
U-Weir 6	6.507	NA	97.08	NA	0.19	97.11	NA	2.10	97.25	NA	NA	NA	NA	2.10	97.*15*	0.14	NA	NH
DROP ST.	7.116	NA	94.11	NA	0.19	94.23	NA	2.10	94.75	**NA**	NA	NA	NA	2.10	94.75	0.52	NA	NA
306 **D5**	8.339	*0.75*	92.91	0.08	0.19	83.73	**0.54**	2.10	93.92	**NA**	NA	NA	0.54	**2.10**	93.92	0.13	0.32	0.104
D-Weir 7	8.342	NA	93.73	NA	0.11	93.73	NA	1.56	93.32	NA	NA	NA	NA	1.56	93.92	**0.19**	NA	NA
309 D4	8.733	0.60	92.50	*0.02*	0.11	93.02	0.27	1.56	93.18	NA	NA	NA	0.27	1.56	93.18	0.16	0.60	0.133
0-Weit. 8	8.737	NA	93. 02	NA	0.09	93.02	NA	1.29	93.18	NA	NA	NA	NA	1.29	93.18	0.16	NA	**NA**
304 05	9.859	0.60	90.21	0.05	0.09	90.81	0.28	1.29	90.48	NA	NA	NA	0.28	1.29	90.98	0.17	0.69	0.124
D-Weir **9**	9.803	NA	90.83	NA	0.05	90.81	NA	1.02	90.98	NA	NA	NA	NA	1.02	90.98	0.17	NA	NA
307 D1	10.502	0.45	**89.31**	0.03	0.05	90. 11	0.21	1.02	90.63	NA	NA	NA	0.21	1.03	90.63	0.52	0.56	**0.464**
307 D2	**10.910**	0.60	89.93	***0.00***	0.02	90. 11	0.19	*0.80*	90.49	NA	NA	NA	0.19	0.80	90.49	0.38	0.37	0.514
307 D3	10.920	0.60	89.85	*0.02*	0.02	'30.11	0.61	0.61	90.49	NA	NA	NA	0.61	0.61	417.45	0.38	0.45	0.422

* - Crest Level in the case of Duckbill Weirs and Drop Structures.

NA - Not Applicable.

Figure 75. Kalankuttiya Branch Channel – Yala 1987
Location: 305 D1 (Station 1)

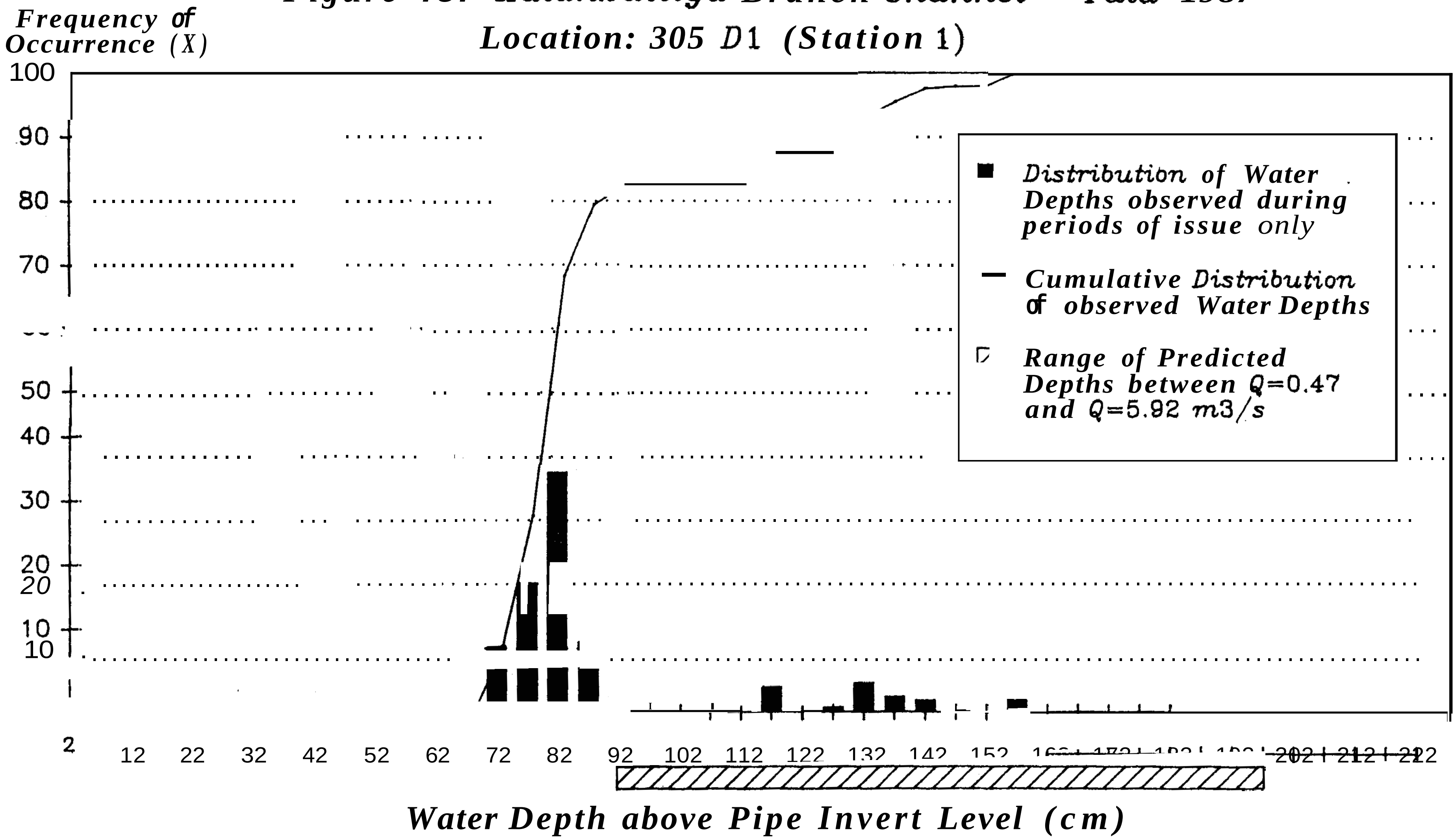


Table 4

KALANKUTTIYA BRANCH CANAL - YALA 87 (13 July 1987 to 07 September 1987)
Distribution of water levels in the Branch Canal above the sill level of each offtake

305-01 (total period) Observ. at MS1			305-01 (period of issue) Observ. at St1			305-02 (total period) Observ. at St2			305-03 (total period) Observ. at St3			308-02 (total period) Observ. at St4			305-04 (total period) Observ. at St5			306-01 (total period) Observ. at St6			308-03 (total period) Observ. at St7			307-01 (total period) Observ. at St10			307-02 (total period) Observ. at St11		
Mid-class	Freq.	Cumul.	Mid-class	Freq.	Cumul.	Mid-class	Freq.	Cumul.	Mid-class	Freq.	Cumul.	Mid-class	Freq.	Cumul.	Mid-class	Freq.	Cumul.	Mid-class	Freq.	Cumul.	Mid-class	Freq.	Cumul.	Mid-class	Freq.	Cumul.	Mid-class	Freq.	Cumul.
0	0.0	0	2	0.0	0	1	0.0	0	1	0.0	0	1	0.0	0	2	0.0	0	0	0.0	0	2	0.0	0	3	0.0	0	1	0.0	0
5	0.0	0	7	0.0	0	6	0.0	0	6	0.0	0	6	0.0	0	7	0.0	0	5	0.0	0	7	0.0	0	8	0.0	0	6	0.0	0
10	0.0	0	12	0.0	0	11	0.0	0	11	0.0	0	11	0.0	0	12	0.0	0	10	0.0	0	12	0.0	0	13	0.0	0	11	0.0	0
15	0.0	0	17	0.0	0	16	0.0	0	16	0.0	0	16	0.0	0	17	0.0	0	15	0.0	0	17	0.0	0	18	0.0	0	16	0.0	0
20	0.0	0	22	0.0	0	21	0.0	0	21	0.0	0	21	0.0	0	22	0.0	0	20	0.0	0	22	0.0	0	23	0.0	0	21	0.0	0
25	0.0	0	27	0.0	0	26	0.0	0	26	0.0	0	26	0.0	0	27	0.0	0	25	0.0	0	27	0.0	0	28	0.0	0	26	14.6	15
30	0.0	0	32	0.0	0	31	0.0	0	31	0.0	0	31	0.0	0	32	0.0	0	30	0.0	0	32	0.0	0	33	0.0	0	31	20.7	35
35	0.0	0	37	0.0	0	36	0.0	0	36	0.0	0	36	0.0	0	37	0.0	0	35	0.0	0	37	0.0	0	38	0.0	0	36	28.1	63
40	0.0	0	42	0.0	0	41	0.0	0	41	0.0	0	41	0.0	0	42	0.0	0	40	0.0	0	42	0.0	0	43	0.0	0	41	21.9	85
45	0.0	0	47	0.0	0	46	0.0	0	46	0.0	0	46	0.0	0	47	0.0	0	45	0.0	0	47	0.0	0	48	0.0	0	46	6.4	92
50	0.0	0	52	0.0	0	51	0.0	0	51	0.0	0	51	0.0	0	52	0.0	0	50	0.0	0	52	0.0	0	53	0.0	0	51	3.4	95
55	0.0	0	57	0.0	0	56	0.0	0	56	0.0	0	56	0.0	0	57	0.0	0	55	0.0	0	57	0.0	0	58	0.0	0	56	1.0	96
60	0.0	0	62	0.0	0	61	0.0	0	61	0.0	0	61	0.0	0	62	0.0	0	60	0.0	0	62	0.0	0	63	4.3	4	61	3.0	99
65	0.0	0	67	0.0	0	66	0.0	0	66	0.0	0	66	0.0	0	67	0.0	0	65	0.0	0	67	0.0	0	68	14.2	19	66	0.7	100
70	0.0	0	72	10.4	10	71	0.0	0	71	0.0	0	71	0.0	0	72	0.0	0	70	0.0	0	72	0.0	0	73	6.7	25	71	0.0	100
75	5.0	5	77	20.3	31	76	0.0	0	76	0.0	0	76	0.0	0	77	0.0	0	75	0.0	0	77	3.3	8	78	23.7	49	76	0.1	100
80	3.3	8	82	37.7	68	81	0.0	0	81	0.0	0	81	0.0	0	82	11.8	12	80	0.0	0	82	0.0	8	83	33.2	82	81	0.0	100
85	5.0	13	87	11.2	80	86	0.0	0	86	0.3	0	86	0.0	0	87	0.0	12	85	0.0	0	87	6.3	15	88	12.7	95	86	0.0	100
90	5.0	18	92	2.9	82	91	0.0	0	91	0.5	1	91	0.5	1	92	5.0	17	90	0.0	0	92	28.6	43	93	0.4	95	91	0.0	100
95	3.3	22	97	0.0	82	96	0.0	0	96	0.5	1	96	19.4	20	97	13.4	30	95	0.0	0	97	56.8	100	98	4.1	99	96	0.0	100
100	8.3	30	102	0.0	82	101	0.0	0	101	1.3	3	101	48.4	68	102	14.6	45	100	0.0	0	102	0.0	100	103	0.0	99	101	0.0	100
105	3.3	33	107	0.0	82	106	0.0	0	106	31.7	34	106	31.6	100	107	0.2	45	105	0.0	0	107	0.0	100	108	0.6	100	106	0.0	100
110	16.7	50	112	0.5	83	111	4.7	5	111	65.6	100	111	0.0	100	112	4.0	49	110	0.0	0	112	0.0	100	113	0.0	100	111	0.0	100
115	13.3	63	117	4.4	87	116	4.4	9	116	0.0	100	116	0.0	100	117	48.6	98	115	0.0	0	117	0.0	100	118	0.0	100	116	0.0	100
120	1.7	65	122	0.0	87	121	4.5	14	121	0.0	100	121	0.0	100	122	2.4	100	120	0.0	0	122	0.0	100	123	0.0	100	121	0.0	100
125	8.3	73	127	0.9	88	126	8.0	22	126	0.0	100	126	0.0	100	127	0.0	100	125	0.0	0	127	0.0	100	128	0.0	100	126	0.0	100
130	5.0	78	132	4.8	93	131	6.7	28	131	0.0	100	131	0.0	100	132	0.0	100	130	0.0	0	132	0.0	100	133	0.0	100	131	0.0	100
135	13.3	92	137	2.6	96	136	21.8	50	136	0.0	100	136	0.0	100	137	0.0	100	135	5.8	6	137	0.0	100	138	0.0	100	136	0.0	100
140	8.3	100	142	2.0	98	141	10.4	60	141	0.0	100	141	0.0	100	142	0.0	100	140	0.0	6	142	0.0	100	143	0.0	100	141	0.0	100
145	0.0	100	147	0.4	98	146	3.2	64	146	0.0	100	146	0.0	100	147	0.0	100	145	3.9	10	147	0.0	100	148	0.0	100	146	0.0	100
150	0.0	100	152	0.0	98	151	6.6	70	151	0.0	100	151	0.0	100	152	0.0	100	150	23.6	33	152	0.0	100	153	0.0	100	151	0.0	100
155	0.0	100	157	2.0	100	156	22.1	92	156	0.0	100	156	0.0	100	157	0.0	100	155	64.0	97	157	0.0	100	158	0.0	100	156	0.0	100
160	0.0	100	162	0.0	100	161	7.6	100	161	0.0	100	161	0.0	100	162	0.0	100	160	2.7	100	162	0.0	100	163	0.0	100	161	0.0	100
165	0.0	100	167	0.0	100	166	0.0	100	166	0.0	100	166	0.0	100	167	0.0	100	165	0.0	100	167	0.0	100	168	0.0	100	166	0.0	100
170	0.0	100	172	0.0	100	171	0.0	100	171	0.0	100	171	0.0	100	172	0.0	100	170	0.0	100	172	0.0	100	173	0.0	100	171	0.0	100
Inter quartile		29			8			30			4			5			20			4			5			9			10
Median		108			78			135			106			98			111			152			92			78			33
Iq/Median		0.27			0.10			0.22			0.04			0.05			0.18			0.03			0.05			0.12			0.30

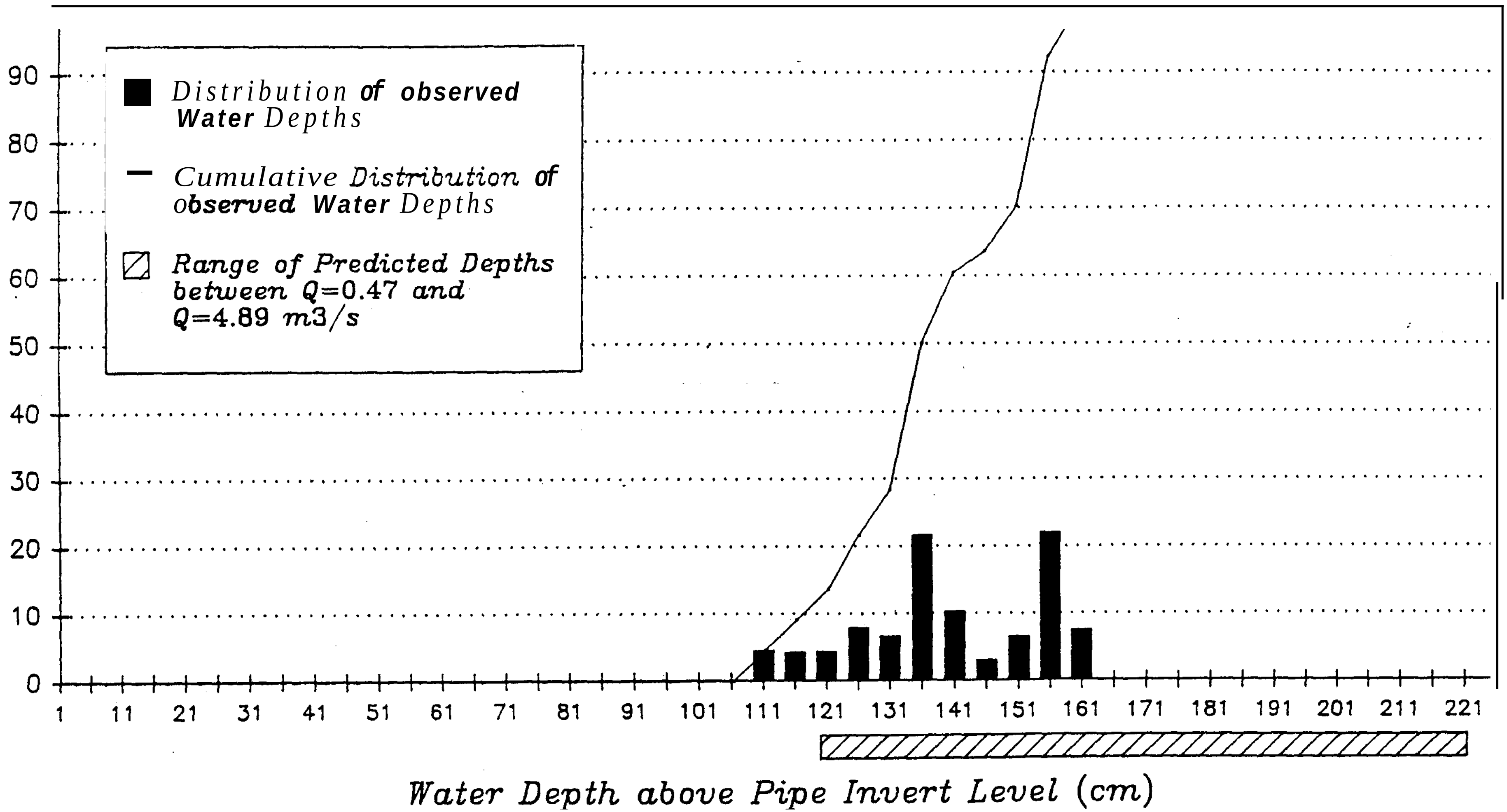

90
80
70
60
50
40
30
20
10
0
Distribution of observed Water Depths
Cumulative Distribution of observed Water Depths
Range of Predicted Depths between Q=0.47 and Q=4.89 m3/s
1
11
21
31
41
51
61
71
81
91
101
111
121
131
141
151
161
171
181
191
201
211
221
Water Depth above Pipe Invert Level (cm)

Figure 17. Kalankuttiya Branch Channel – Yala 1987

Location: 305 D3 (Station 3)

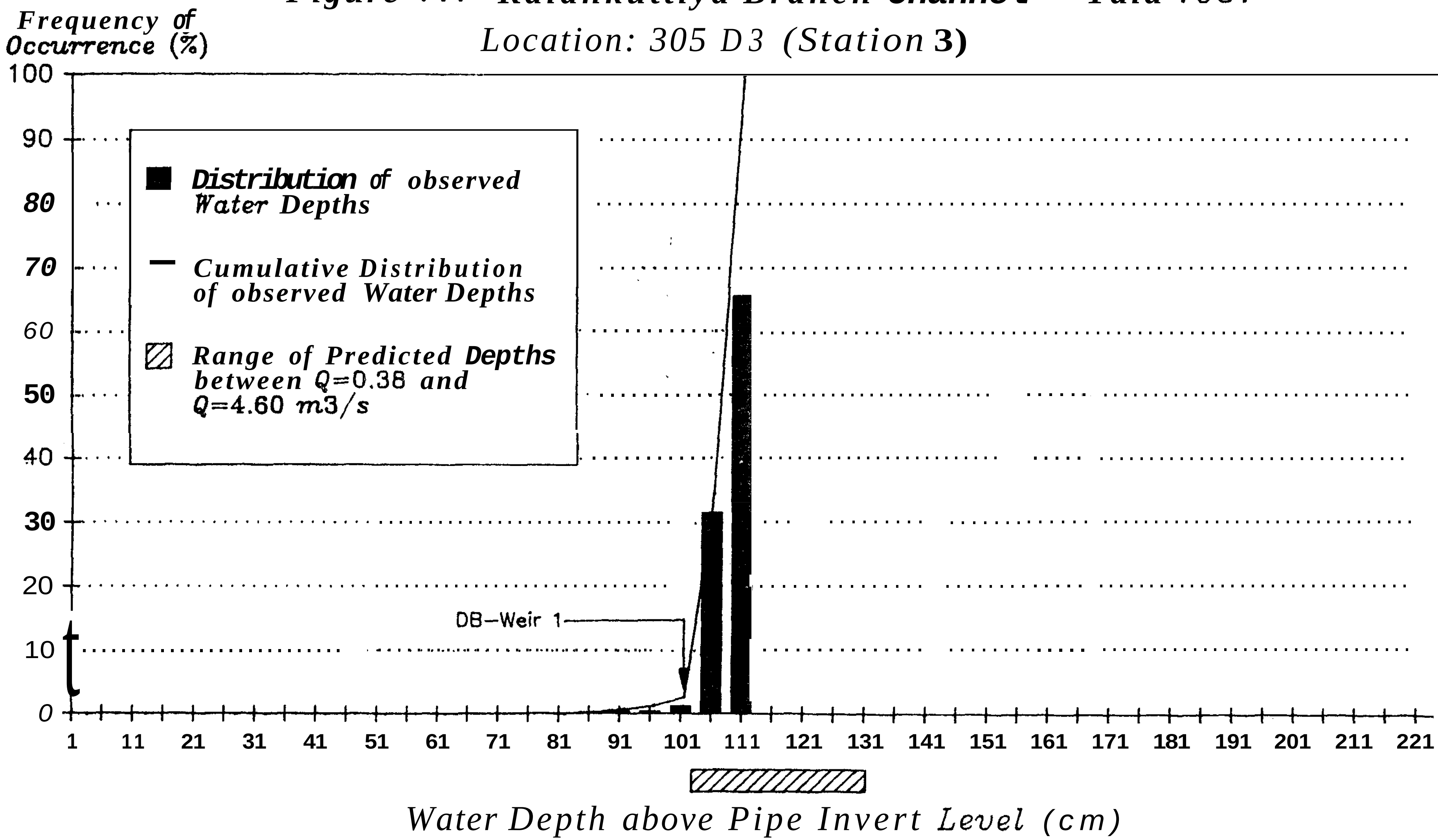
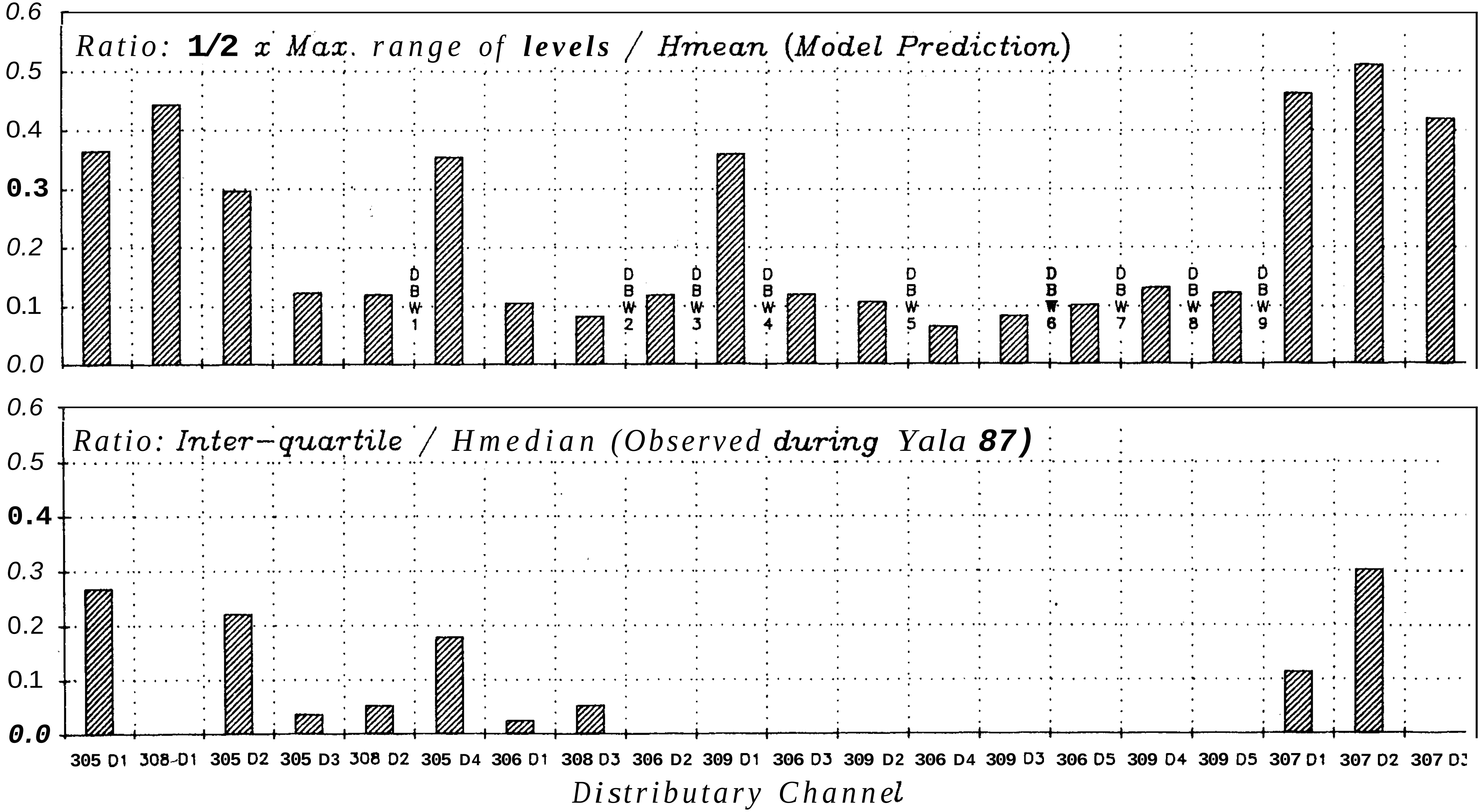


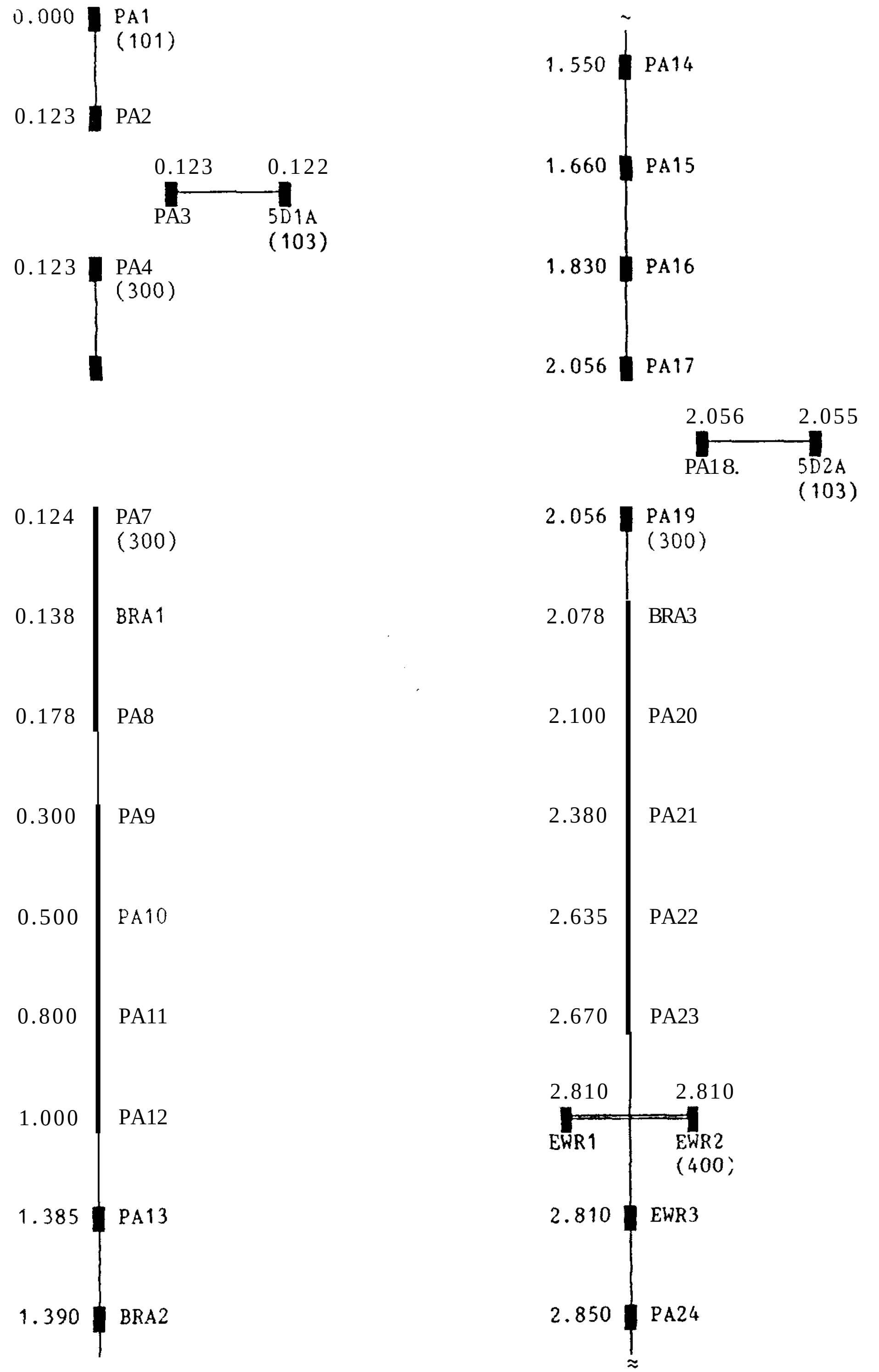
Figure 18. *Kalankuttiya Branch Channel*



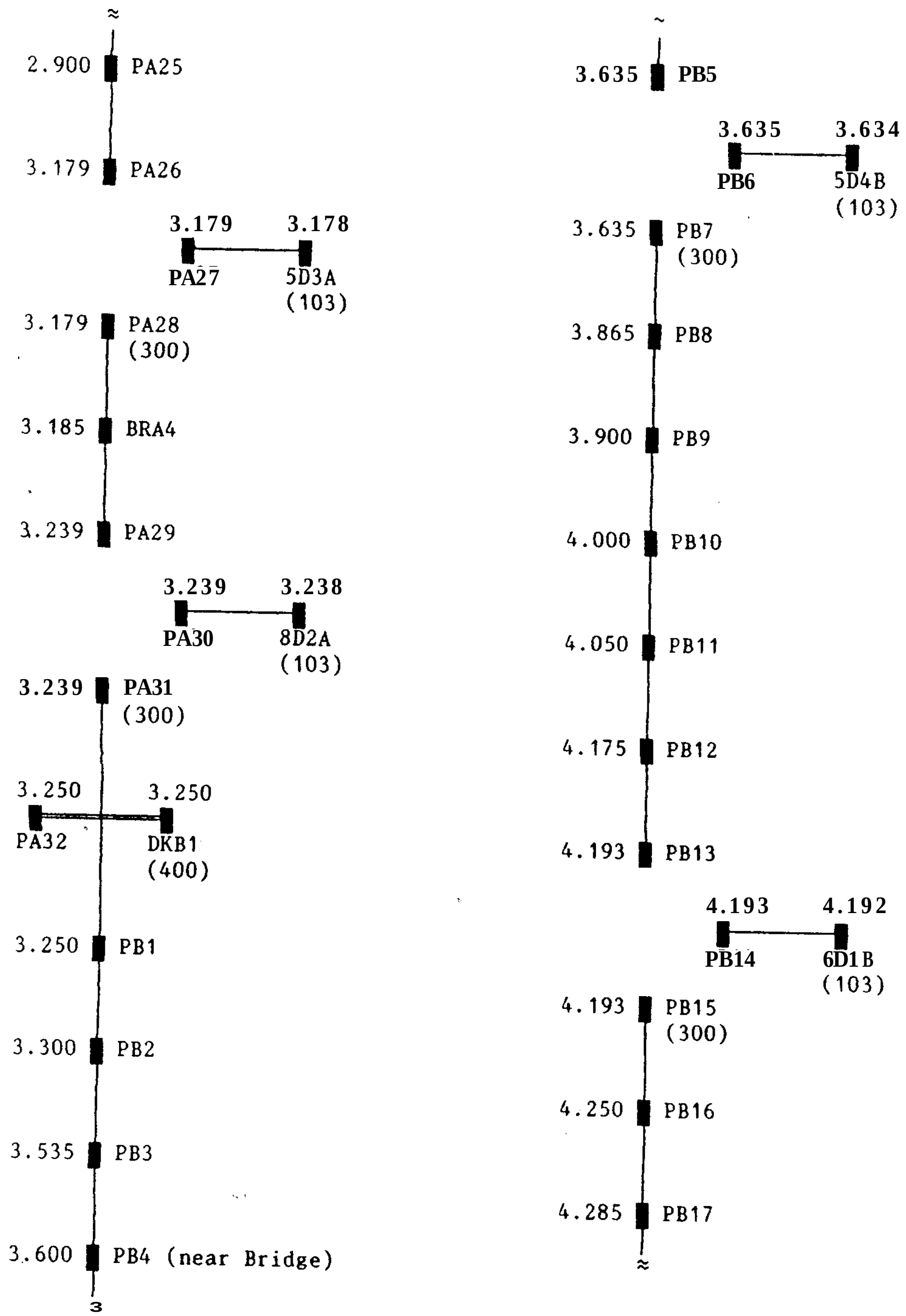
APPENDIX A

Figure A1. **Schematic diagram of computational points for the entire channel.**

(The symbol ▮ represents the computational points, appropriately labeled. The convention adopted for the nomenclature is the same as that used for Figure 4, and is described on pages 10 and 11.)

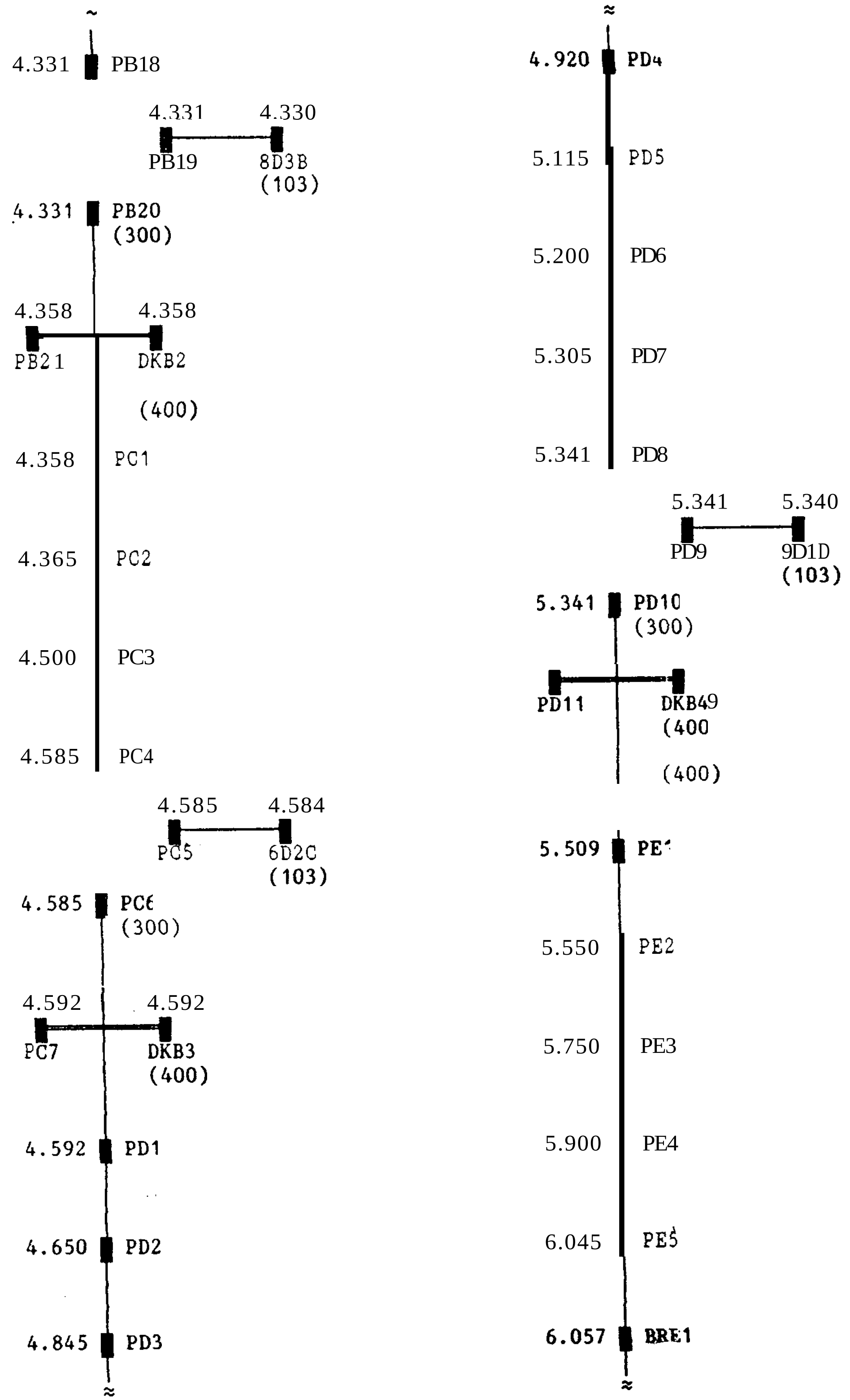


(Continued...)



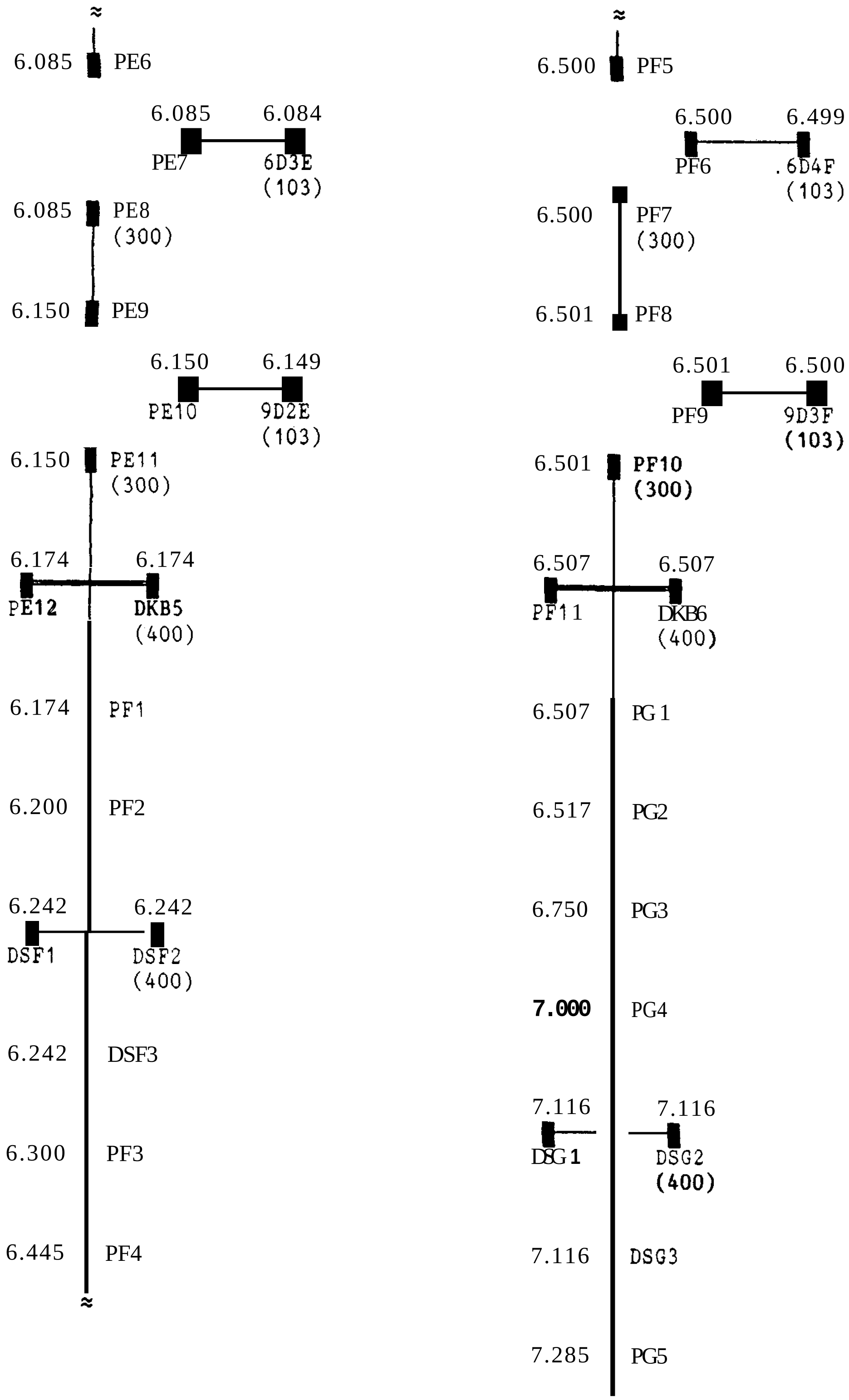
2.900 PA25
3.179 PA26
3.179 3.178
PA27 5D3A (103)
3.179 PA28 (300)
3.185 BRA4
3.239 PA29
3.239 3.238
PA30 8D2A (103)
3.239 PA31 (300)
3.250 3.250
PA32 DKB1 (400)
3.250 PB1
3.300 PB2
3.535 PB3
3.600 PB4 (near Bridge)
3.635 PB5
3.635 3.634
PB6 5D4B (103)
3.635 PB7 (300)
3.865 PB8
3.900 PB9
4.000 PB10
4.050 PB11
4.175 PB12
4.193 PB13
4.193 4.192
PB14 6D1B (103)
4.193 PB15 (300)
4.250 PB16
4.285 PB17

(Continued...)

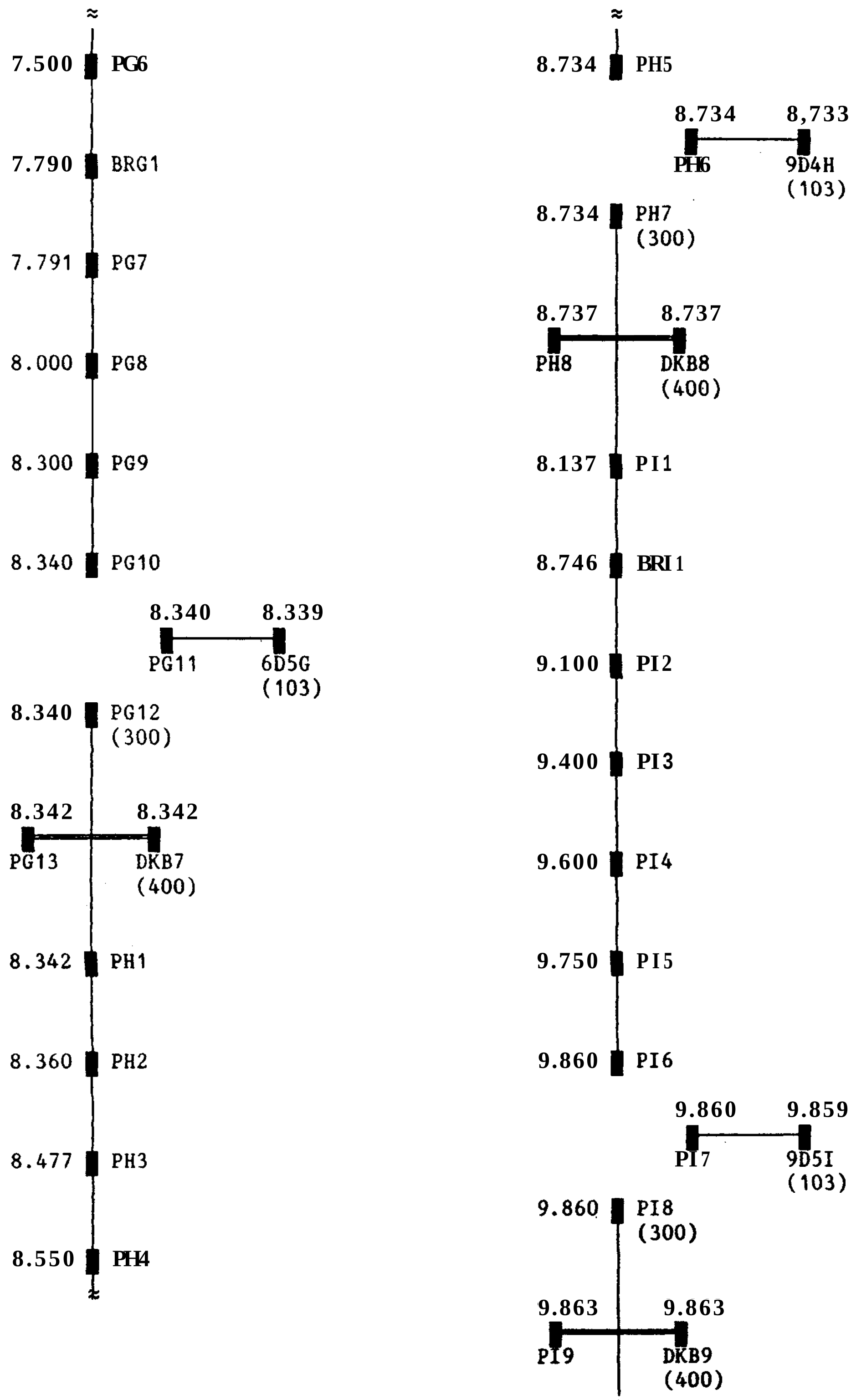


4.331 PB18
4.331 4.330
PB19 8D3B (103)
4.331 PB20 (300)
4.358 4.358
PB21 DKB2
(400)
4.358 PC1
4.365 PC2
4.500 PC3
4.585 PC4
4.585 4.584
PC5 6D2C (103)
4.585 PC6 (300)
4.592 4.592
PC7 DKB3 (400)
4.592 PD1
4.650 PD2
4.845 PD3
4.920 PD4
5.115 PD5
5.200 PD6
5.305 PD7
5.341 PD8
5.341 5.340
PD9 9D1D (103)
5.341 PD10 (300)
PD11 DKB49 (400
(400)
5.550 PE2
5.750 PE3
5.900 PE4
6.045 PE5
6.057 BRE1

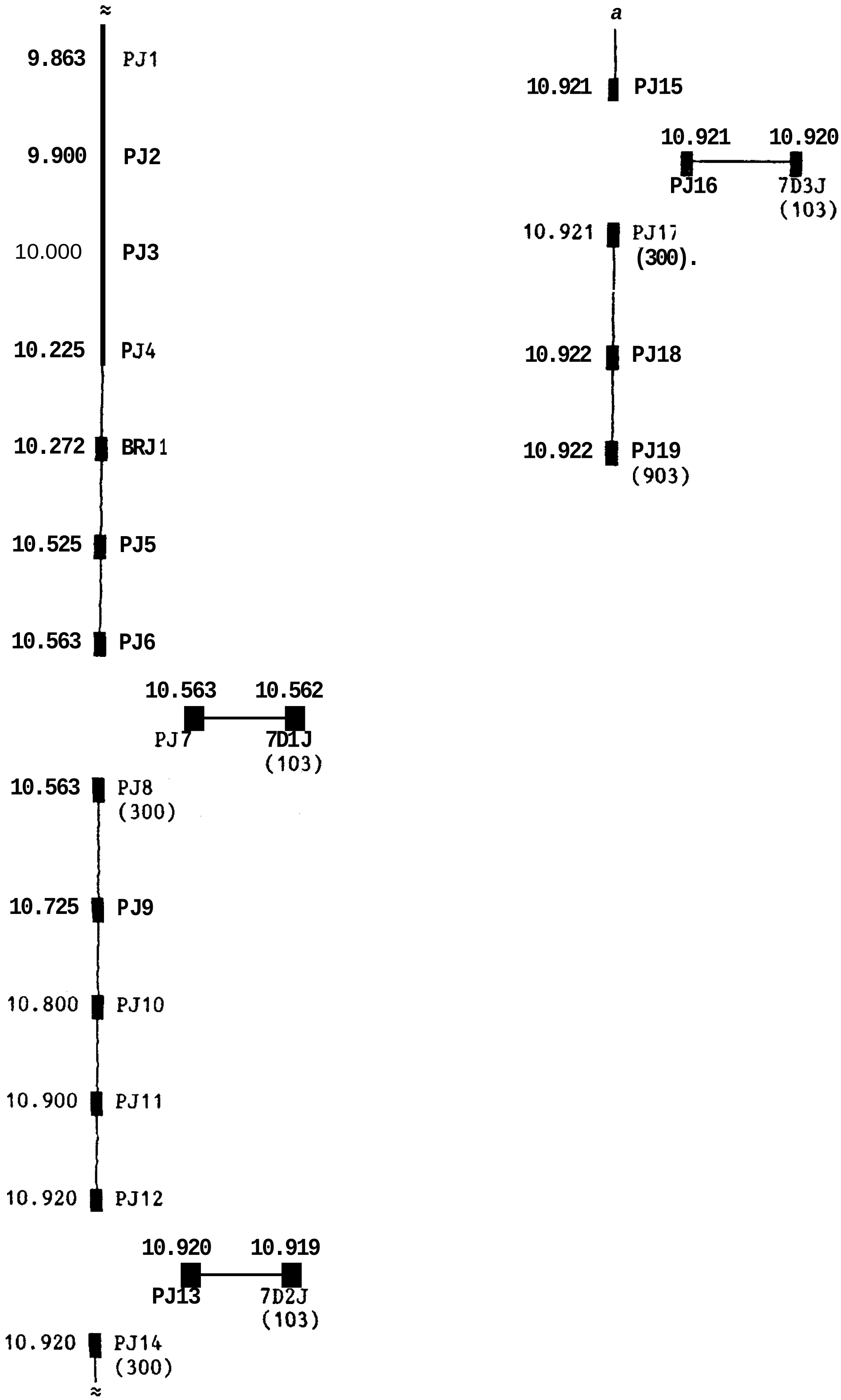
(Continued..)


6.085 PE6
6.085 6.084
PE7 6D3E (103)
6.085 PE8 (300)
6.150 PE9
6.150 6.149
PE10 9D2E (103)
6.150 PE11 (300)
6.174 6.174
PE12 DKB5 (400)
6.174 PF1
6.200 PF2
6.242 6.242
DSF1 DSF2 (400)
6.242 DSF3
6.300 PF3
6.445 PF4
6.500 PF5
6.500 6.499
PF6 .6D4F (103)
6.500 PF7 (300)
6.501 PF8
6.501 6.500
PF9 9D3F (103)
6.501 PF10 (300)
6.507 6.507
PF11 DKB6 (400)
6.507 PG1
6.517 PG2
6.750 PG3
7.000 PG4
7.116 7.116
DSG1 DSG2 (400)
7.116 DSG3
7.285 PG5

(Continued.. .)



7.500 PG6
7.790 BRG1
7.791 PG7
8.000 PG8
8.300 PG9
8.340 PG10
8.340 PG11
8.339 6D5G (103)
8.340 PG12 (300)
8.342 PG13
8.342 DKB7 (400)
8.342 PH1
8.360 PH2
8.477 PH3
8.550 PH4
8.734 PH5
8.734 PH6
8,733 9D4H (103)
8.734 PH7 (300)
8.737 PH8
8.737 DKB8 (400)
8.137 PI1
8.746 BRI1
9.100 PI2
9.400 PI3
9.600 PI4
9.750 PI5
9.860 PI6
9.860 PI7
9.859 9D5I (103)
9.860 PI8 (300)
9.863 PI9
9.863 DKB9 (400)



a
9.863 PJ1
9.900 PJ2
10.000 PJ3
10.225 PJ4
10.272 BRJ1
10.525 PJ5
10.563 PJ6
10.563 PJ7
10.562 7D1J (103)
10.563 PJ8 (300)
10.725 PJ9
10.800 PJ10
10.900 PJ11
10.920 PJ12
10.920 PJ13
10.919 7D2J (103)
10.920 PJ14 (300)
10.921 PJ15
10.921 PJ16
10.920 7D3J (103)
10.921 PJ17 (300).
10.922 PJ18
10.922 PJ19 (903)

Figure A2. Kalankuttiya Branch Channel

Water Surface Profiles (Steady flow simulations)

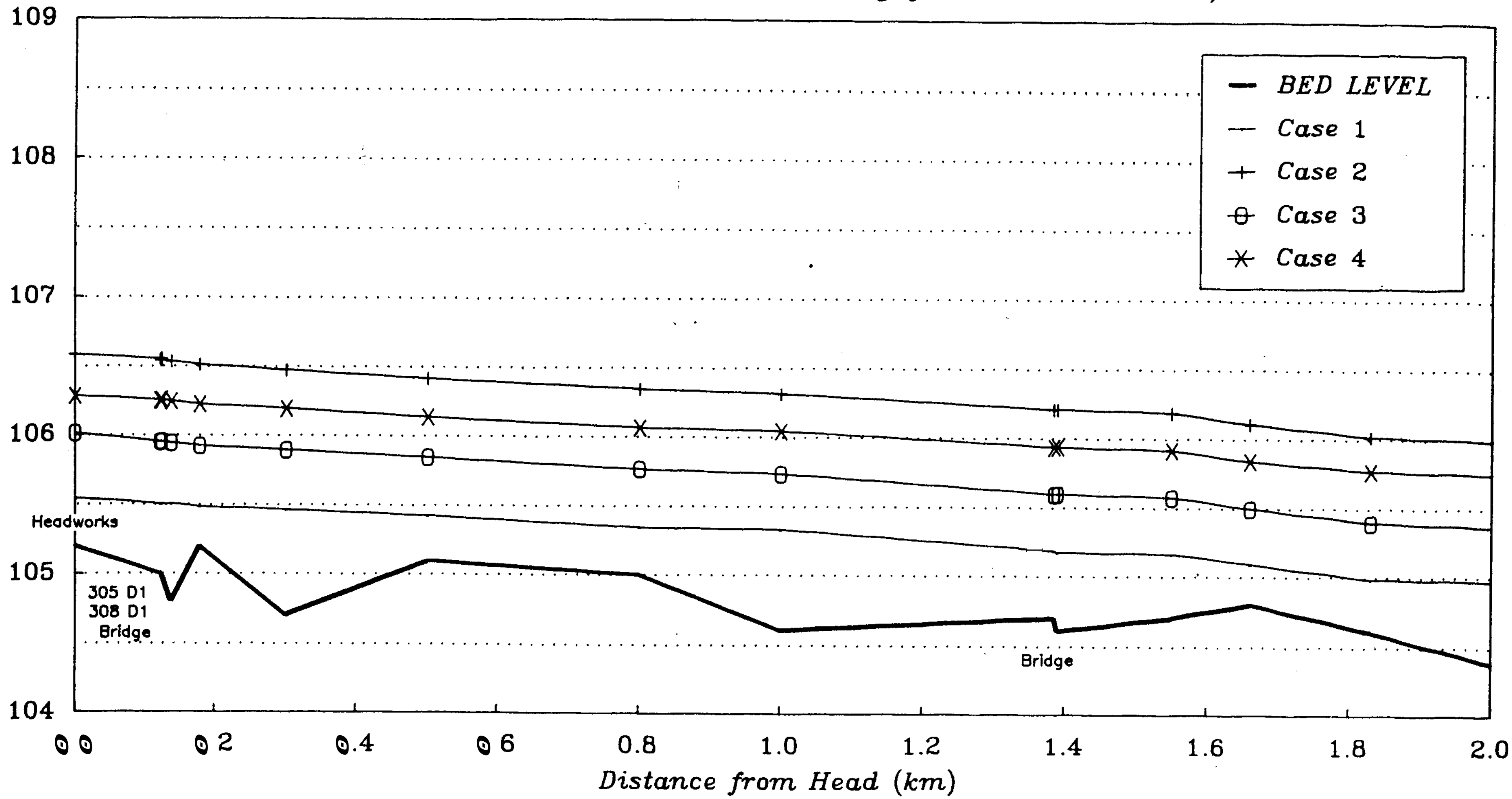


Figure A3. Kalankuttiya Branch Channel

Water Surface Profiles (Steady flow simulations)

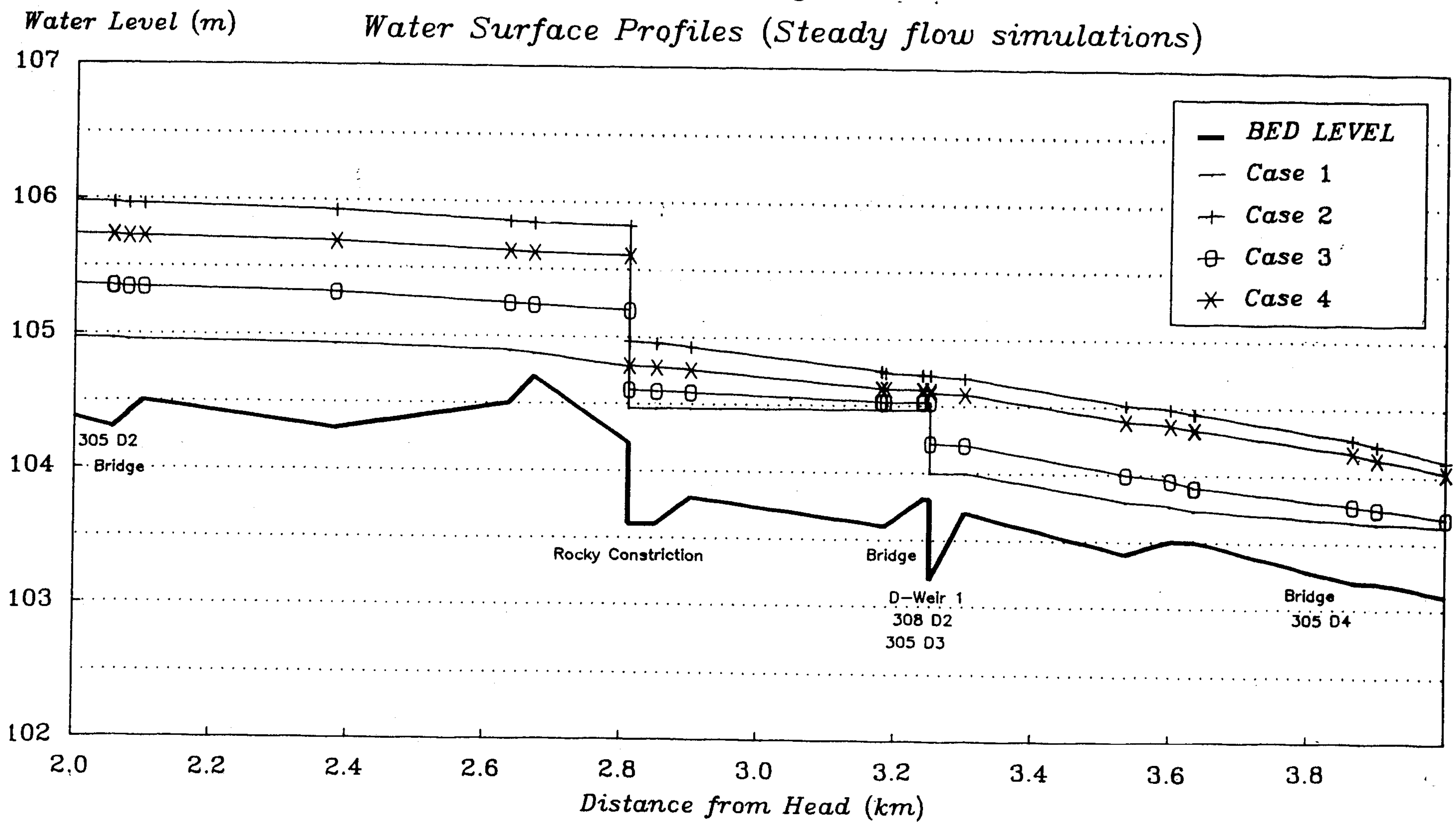


Figure A4. Kalankuttiya Branch Channel Water Surface Profiles (Steady flow simulations)

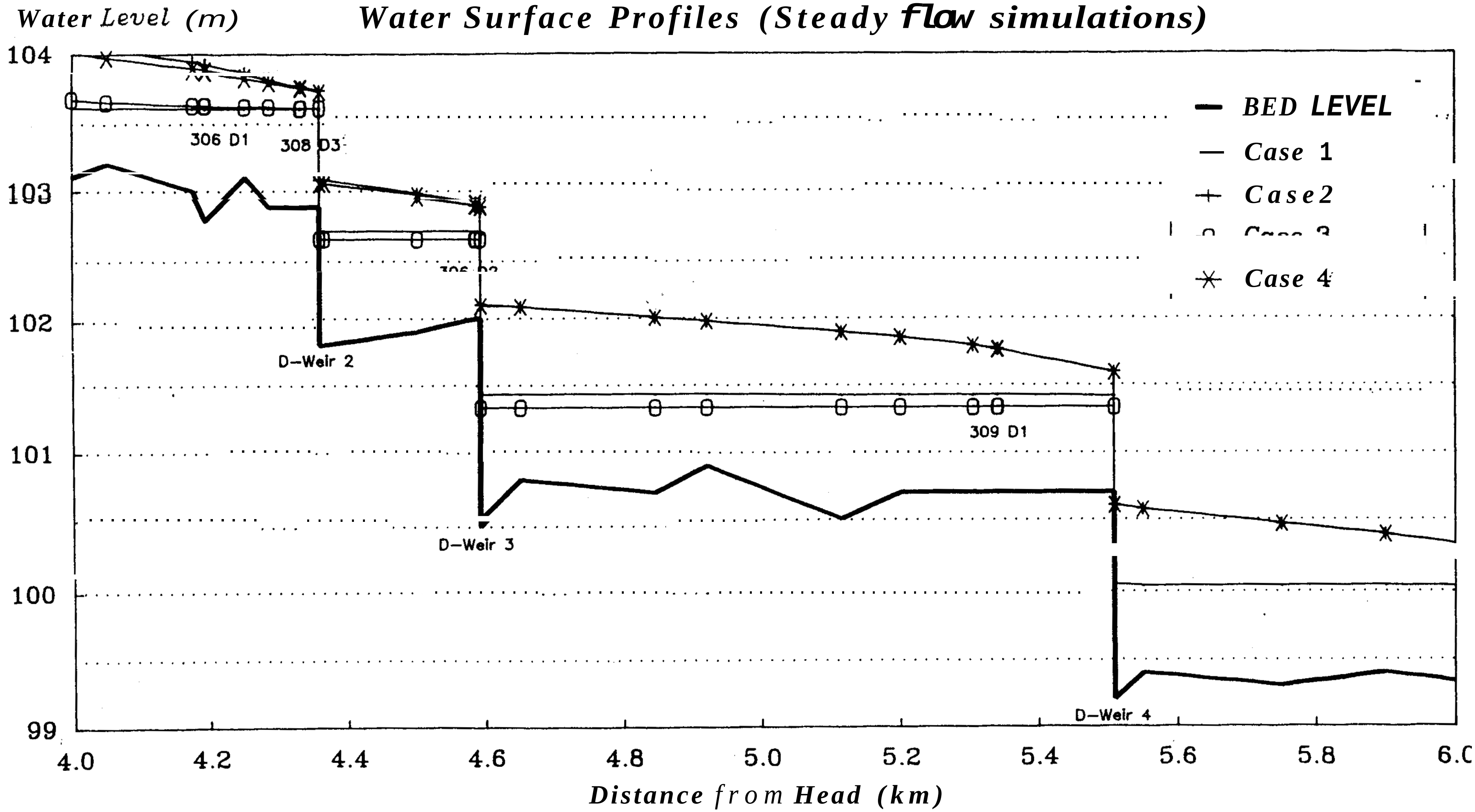


Figure A5. Kalankuttiya Branch Channel

Water Surface Profiles (Steady flow simulations)

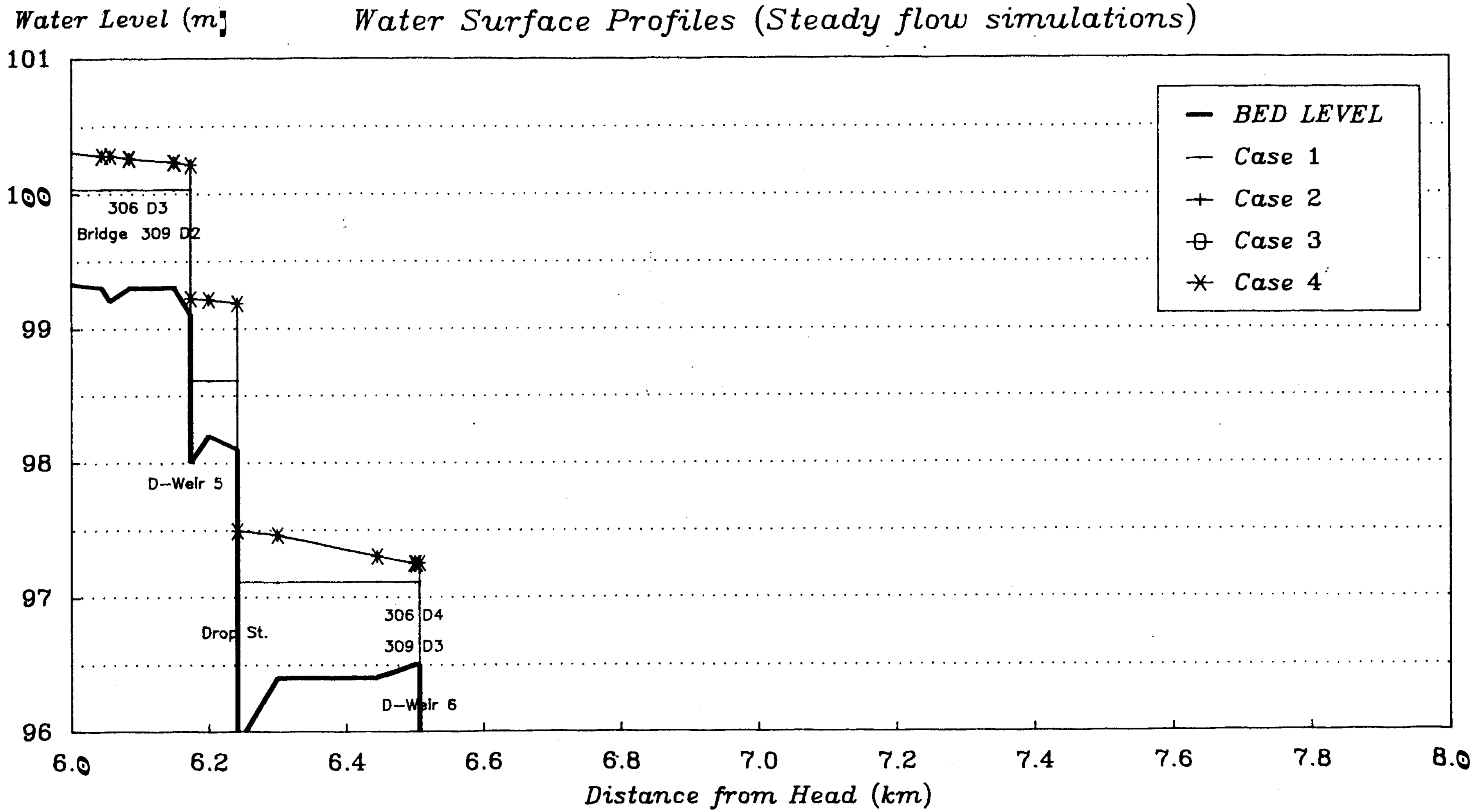


Figure A6. Kalankuttiya Branch Channel

Water Surface Profiles (Steady flow simulations)

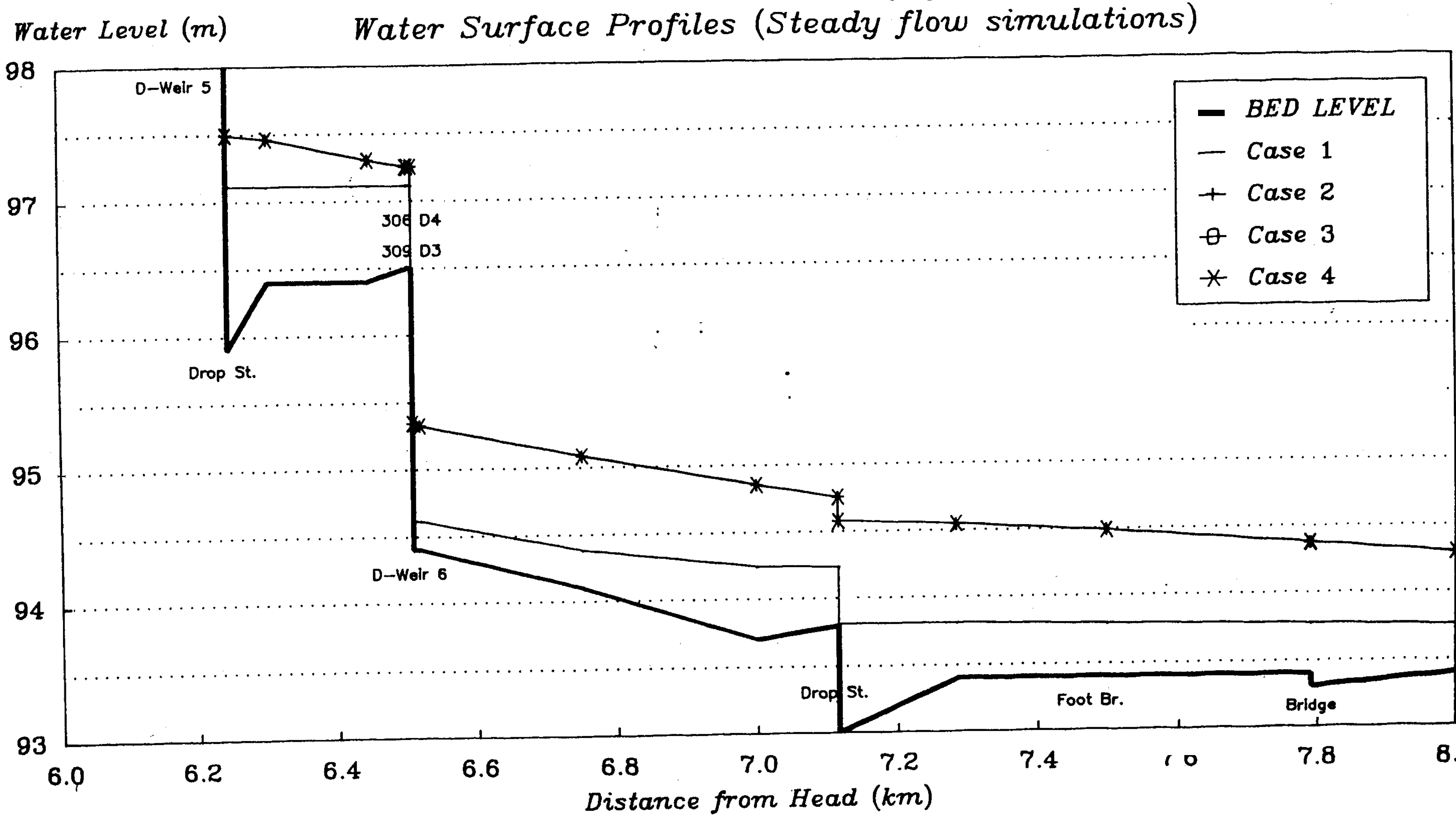


Figure A7. Kalankuttiya Branch Channel

Water Surface Profiles (Steadyflow simulations)

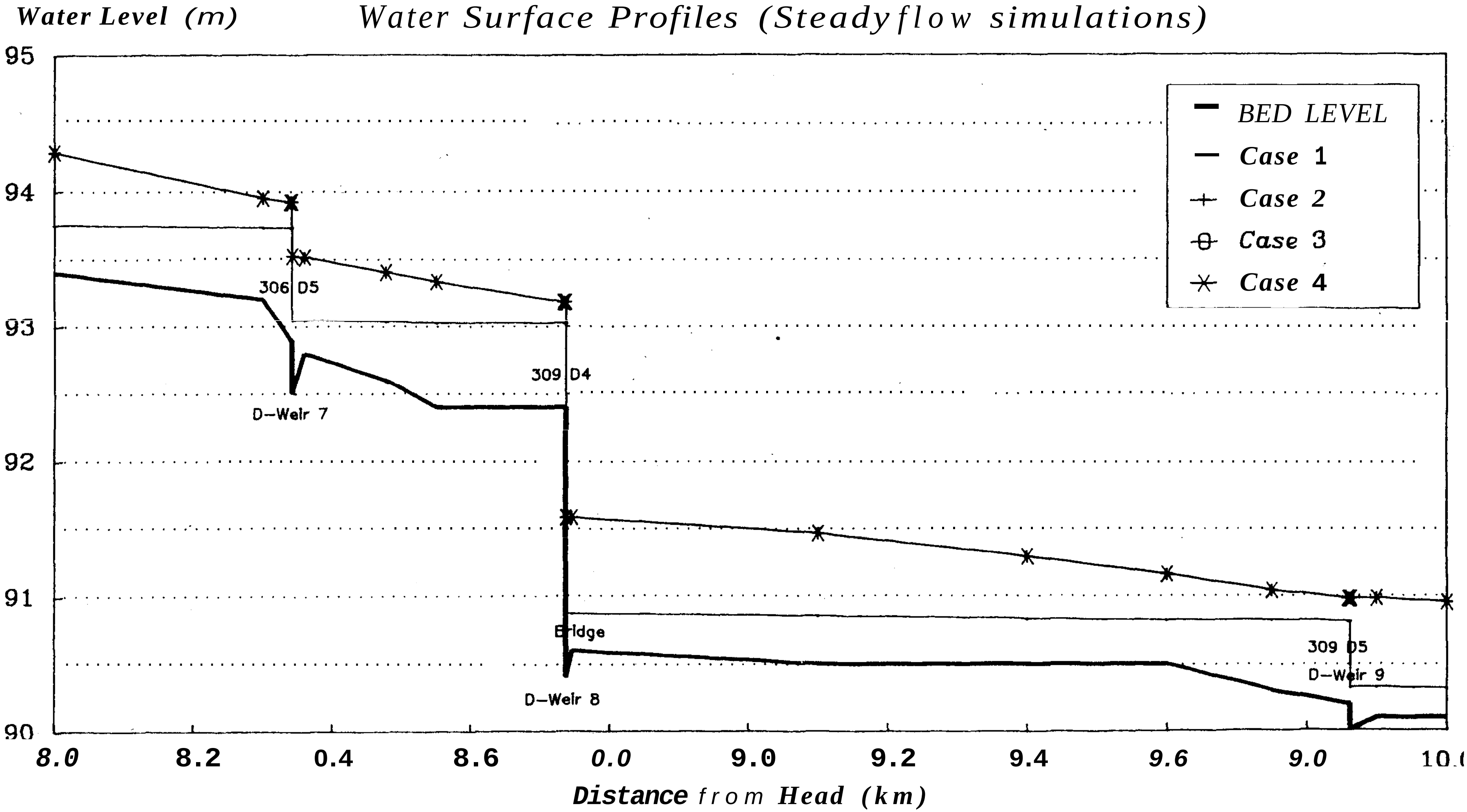


Figure A8. *Kalankuttiya Branch Channel*

Water Surface Profiles (Steadyflow simulations)

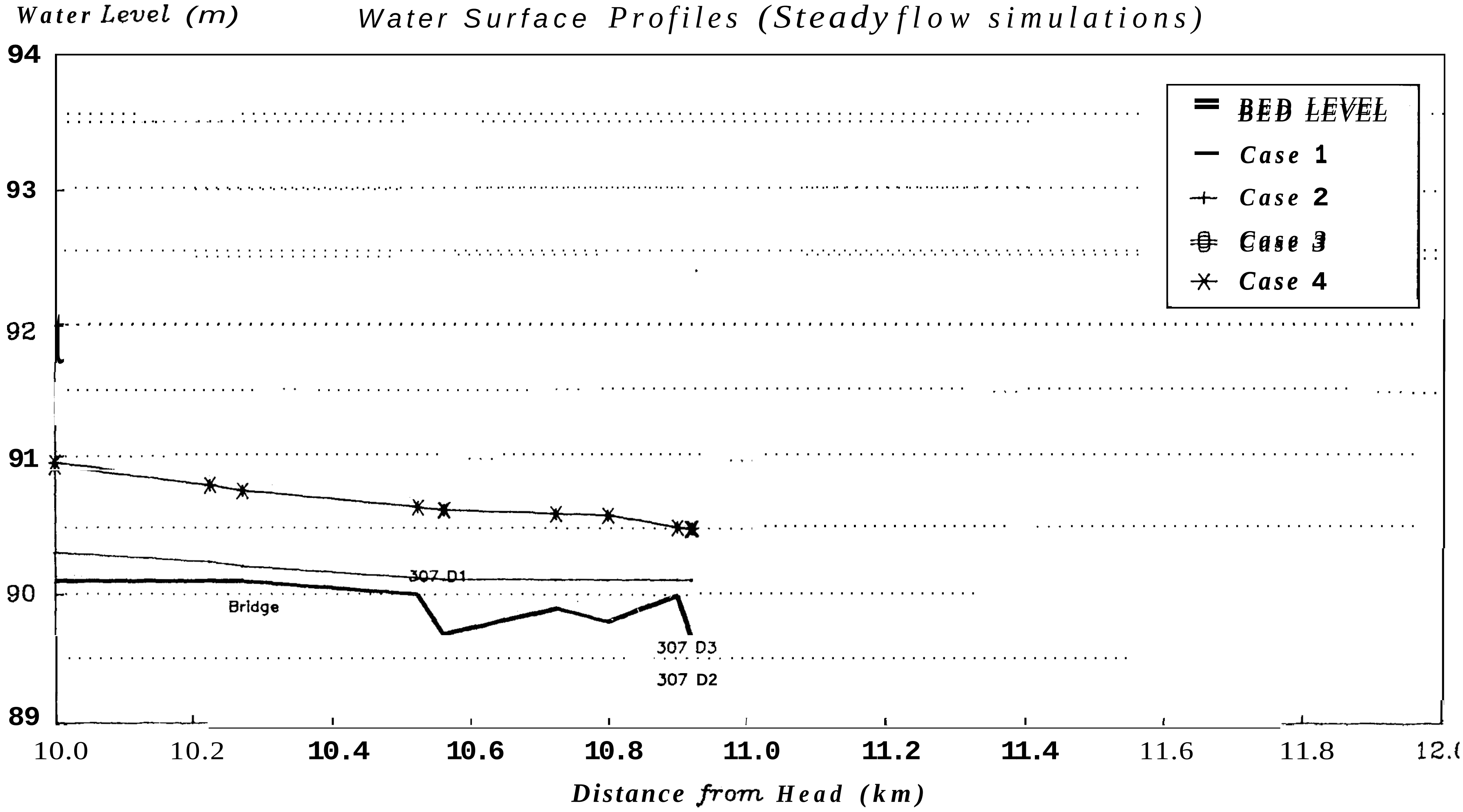


Figure A9. Kalankuttiya Branch Channel
Water Surface Profiles (Steadyflow simulations)

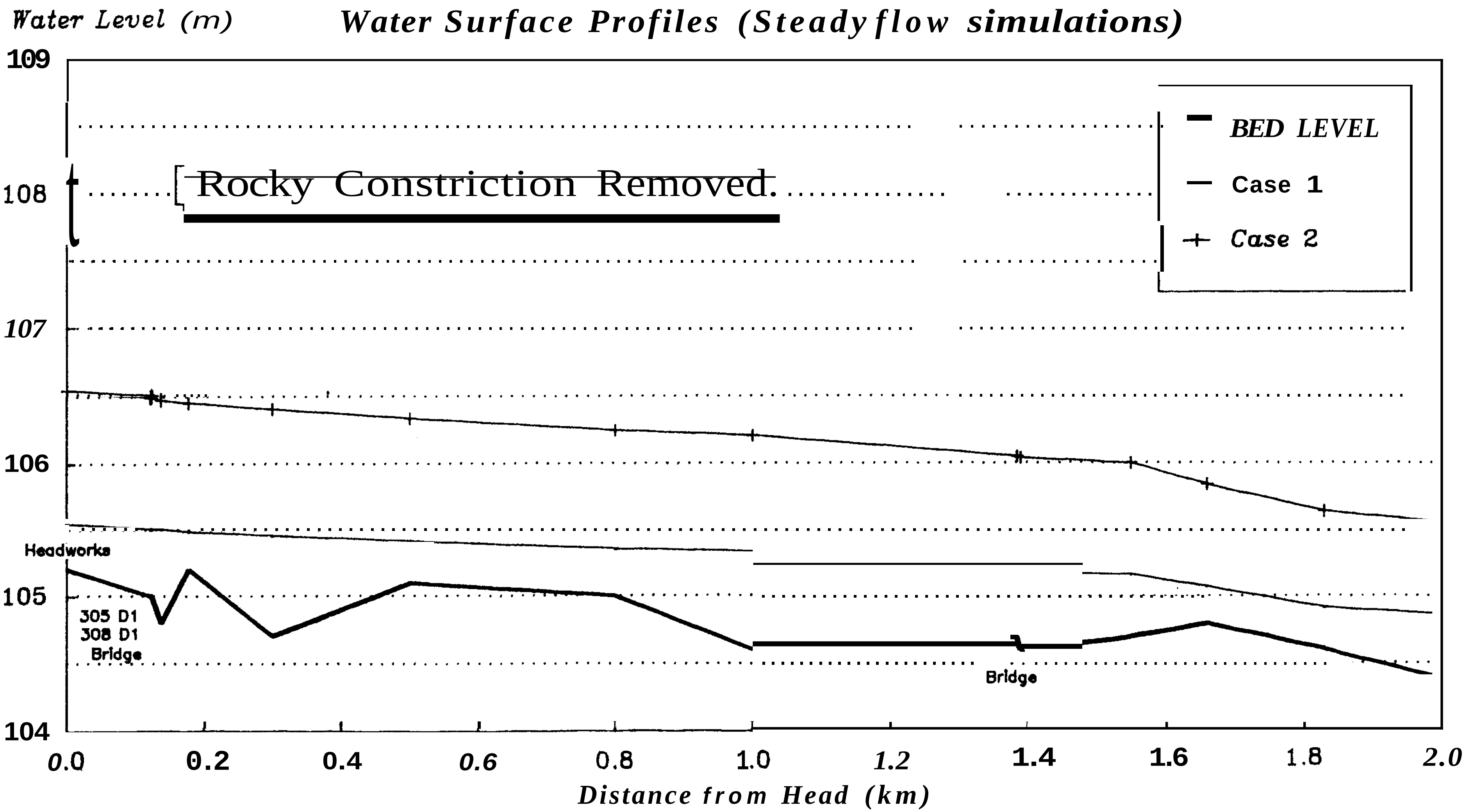
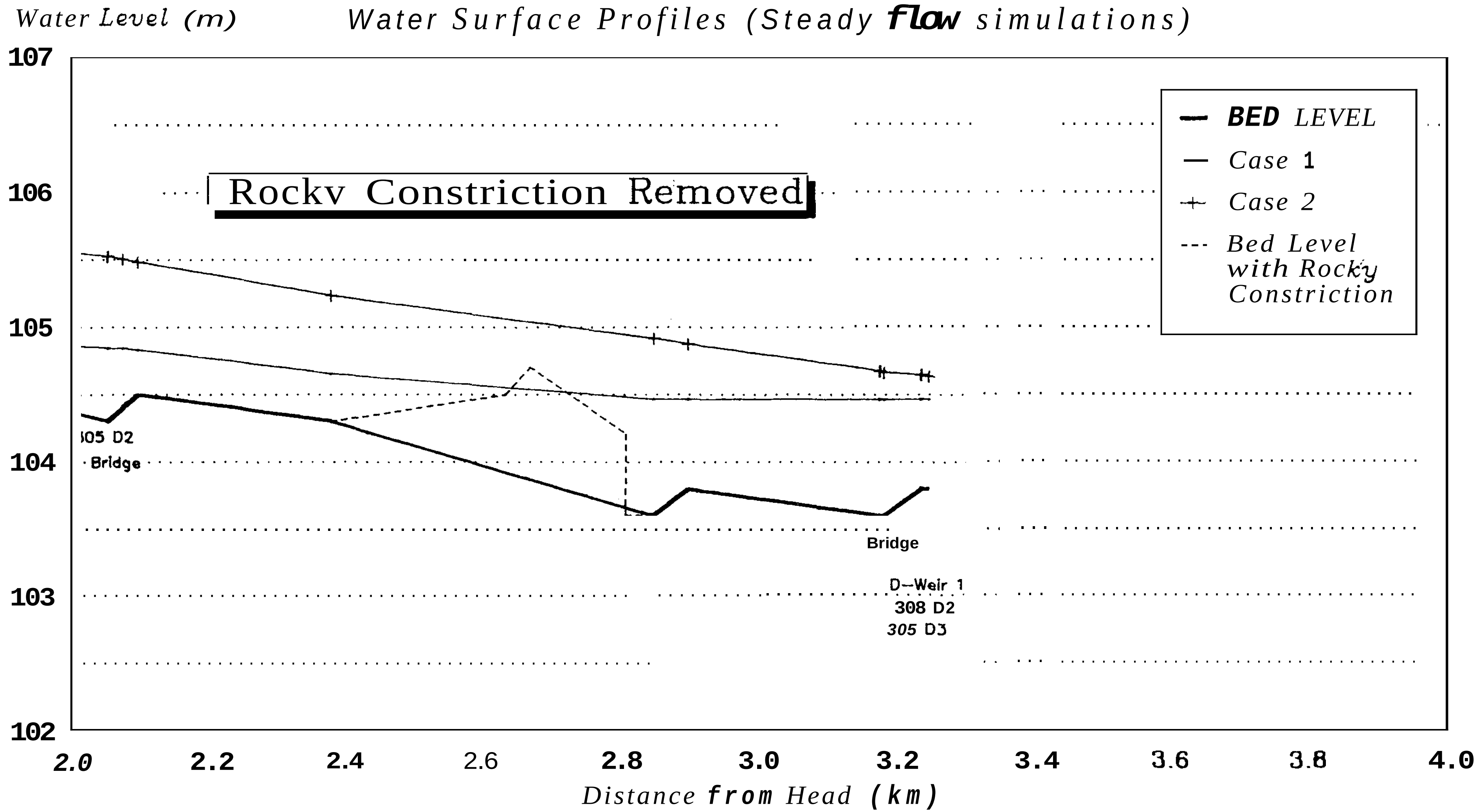


Figure A 10. *Kalankuttiya* Braneh Channel

Water Surface Profiles (Steady **flow** simulations)



APPENDIX B

Table B1. Results generated in terms of water level, discharge, and velocity.

Point	Case 1			Case 2			Case 3			Case 4		
	Discharge (m3/s)	Water level (m)	Velocity (m/s)	Discharge (m3/s)	Water level (m)	Velocity (m/s)	Discharge (m3/s)	Water level (m)	Velocity (m/s)	Discharge (m3/s)	Water Level (m)	Velocity (m/s)
PA1	.47	105.54	.32	5.92	106.58	.67	2.90	106.01	.68	3.24	106.28	.52
PA2	.47	105.50	.10	5.92	106.55	.43	2.90	105.95	.34	3.24	106.25	.29
5D1A	-.00	105.50	-.00	-.84	106.55	-.06	-.84	105.95	-.10	-.00	106.25	.00
PA3	-.00	105.50	-.00	-.84	106.55	-.06	-.84	105.95	-.10	-.00	106.25	.00
PA4	.47	105.50	.10	5.08	106.55	.37	2.06	105.95	.24	3.23	106.25	.29
PA5	.47	105.50	.10	5.08	106.54	.37	2.06	105.95	.25	3.23	106.25	.29
8D1A	.00	105.50	.00	-.19	106.54	-.01	-.19	105.95	-.02	.00	106.25	.00
PA6	.00	105.50	.00	-.19	106.54	-.01	-.19	105.95	-.02	.00	106.25	.00
PA7	.47	105.50	.10	4.89	106.54	.36	1.87	105.95	.22	3.23	106.25	.29
BRA1	.47	105.50	.17	4.89	106.53	.68	1.87	105.94	.42	3.23	106.24	.56
PA8	.47	105.48	.27	4.89	106.51	.57	I.87	105.92	.43	3.23	106.22	.51
PA9	.47	105.46	.14	4.89	106.47	.51	1.87	105.89	.33	3.23	106.19	.43
PA10	.47	105.42	.24	4.89	106.41	.53	1.87	105.84	.40	3.23	106.13	.46
PA11	.47	105.34	.18	4.89	106.34	.41	1.87	105.76	.30	3.23	106.06	.35
PA12	.47	105.33	.12	4.89	106.31	.35	1.87	105.73	.25	3.23	106.04	.30
PA13	.47	105.18	.33	4.89	106.20	.51	1.87	105.59	.47	3.23	105.93	.47
BRA2	.47	105.17	.12	4.89	106.20	.48	1.87	105.59	.29	3.23	105.93	.38
PA14	.47	105.16	.15	4.89	106.18	.38	1.87	105.57	.29	3.23	105.91	.33
PA15	.47	105.09	.40	4.89	106.10	.76	1.87	105.49	.63	3.23	105.83	.68
PA16	.47	104.98	.21	4.89	106.01	.44	1.87	105.39	.35	3.23	105.76	.38
PA17	147	104.96	.11	4.89	105.97	.37	1.87	105.35	.25	3.23	105.73	.30
5D2A	-.08	104.96	-.02	-.29	105.97	-.02	-.29	105.35	-.04	-.08	105.73	-.00
PA18	-.08	104.96	-.02	-.29	105.97	-.02	-.29	105.35	-.04	-.08	105.73	-.00
PA19	.38	104.96	.09	4.60	105.97	.35	1.58	105.35	.21	3.15	105.73	.29
BRA3	.38	104.95	.11	4.60	105.96	.47	1.58	105.34	.27	3.15	105.72	.38
PA20	.38	104.95	.16	4.60	105.96	.36	1.58	105.34	.27	3.15	105.72	.32
PA21	.38	104.93	.10	4.60	105.92	.32	1.58	105.31	.22	3.15	105.69	.27
PA22	.38	104.89	.22	4.60	105.85	.54	1.58	105.24	.40	3.15	105.63	.47
PA23	.38	104.87	.28	4.60	105.84	.38	1.58	105.23	.32	3.15	105.62	.34
EWR1	.38	104.77	.10	4.60	105.82	.33	1.58	105.19	.22	3.15	105.60	.28
EWR2	.38	104.77	.10	4.60	105.82	.33	1.58	105.19	.22	3.15	105.60	.28
EWR3	.38	104.46	.07	4.60	104.96	.54	1.58	104.60	.26	3.15	104.78	.43
PA24	.38	104.46	.07	4.60	104.95	.54	1.58	104.59	.26	3.15	104.77	.43
PA25	.38	104.46	.10	4.60	104.92	.68	1.58	104.58	.36	3.15	104.75	.57
PA26	.38	104.46	.07	4.60	104.75	.63	1.58	104.52	.28	3.15	104.62	.49
5D3A	-.05	104.46	-.00	-.33	104.75	-.05	-.33	104.52	-.06	-.05	104.62	-.00
PA27	-.05	104.46	-.00	-.33	104.75	-.05	-.33	104.52	-.06	-.05	104.62	-.00
PA28	.33	104.46	.06	4.27	104.75	.59	1.25	104.52	.22	3.10	104.62	.49
BRA4	.33	104.46	.07	4.27	104.74	.68	1.25	104.52	.24	3.10	104.62	.55
PA29	.33	104.46	.05	4.27	104.72	.43	1.25	104.52	.16	3.10	104.61	.36
8D2A	-.00	104.46	.00	-.19	104.72	-.02	-.19	104.52	-.02	-.00	104.61	.00
PA30	-.00	104.46	.00	-.19	104.72	-.02	-.19	104.52	-.02	-.00	104.61	.00
PA31	.33	104.46	.05	4.08	104.72	.41	1.06	104.52	.14	3.10	104.61	.36
PA32	.33	104.46	.05	4.08	104.72	.41	1.06	104.52	.14	3.10	104.61	.36
DKB1	.33	104.46	.05	4.08	104.72	.41	1.06	104.52	.14	3.10	104.61	.34

contd.

Point	Case 1			Case 2			Case 3			Case 4		
	Discharge (m3/s)	Water level (m)	Velocity (m/s)	Discharge (m3/s)	Water level (m)	Velocity (m/s)	Discharge (m3/s)	Water level (m)	Velocity (m/s)	Discharge (m3/s)	Water level (m)	Velocity (m/s)
PB1	.33	103.99	.03	4.08	104.72	.21	1.06	104.21	.08	3.10	104.59	.17
PB2	.33	103.99	.28	4.08	104.70	.58	1.06	104.20	.41	3.10	104.58	.54
P83	.33	103.79	.17	4.08	104.51	.44	1.06	103.99	.28	3.10	104.39	.39
PB4	.33	103.76	.12	4.08	104.48	.36	1.06	103.95	.21	3.10	104.36	.31
P85	.33	103.73	.22	4.08	104.45	.51	1.06	103.90	.39	3.10	104.33	.45
5D4B	-.02	103.73	-.01	-.21	104.45	-.03	-.21	103.90	-.08	-.02	104.33	-.00
PB6	-.02	103.73	-.01	-.21	104.45	-.03	-.21	103.90	-.08	-.02	104.33	-.00
PB7	.31	103.73	.21	3.87	104.45	.48	185	103.90	.31	3.08	104.33	.45
PB8	.31	103.65	.12	3.87	104.26	.56	.85	103.77	.25	3.08	104.16	.51
P89	.31	103.64	.18	3.87	104.22	.66	.85	103.75	.36	3.08	104.12	.60
PB10	.31	103.62	.10	3.87	104.10	.64	.85	103.60	.25	3.08	104.02	.56
PB11	.31	103.62	.12	3.87	104.04	.64	.85	103.66	.29	3.08	103.97	.57
PB12	.31	103.61	.06	3.81	103.94	.46	.85	103.63	.17	3.08	103.89	.39
PB13	.31	103.61	.06	3.87	103.92	.50	.85	103.63	.16	3.08	103.88	.42
6D1B	-.02	103.61	-.00	-.25	103.92	-.03	-.25	103.63	-.05	-.02	103.88	-.00
PB14	-.02	103.61	-.00	-.25	103.92	-.03	-.25	103.63	-.05	-.02	103.88	-.00
PB15	.29	103.61	.05	3.62	103.92	.47	.60	103.63	.11	3.06	103.88	.42
PB16	.29	103.61	.08	3.62	103.86	.60	.60	103.62	.16	3.06	103.83	.54
PB17	.29	103.61	.06	3.62	103.82	.58	.60	103.62	.13	3.06	103.80	.51
PB18	.29	103.61	.06	3.62	103.77	.62	.60	103.61	.13	3.06	103.76	.53
8D3B	-.00	103.61	-.00	-.29	103.77	-.05	-.29	103.61	-.06	-.00	103.76	-.00
PB19	-.00	103.61	-.00	-.29	103.77	-.05	-.29	103.61	-.06	-.00	103.76	-.00
PB20	.28	103.61	.06	3.33	103.77	.57	.32	103.61	.07	3.05	103.76	.53
PB21	.28	103.61	.06	3.33	103.74	.59	.32	103.61	.07	3.05	103.73	.55
DKB2	.28	103.61	.06	3.33	103.74	.59	.32	103.61	.07	3.05	103.73	.55
PC1	.28	102.72	.03	3.33	103.08	.23	.32	102.66	.03	3.05	103.05	.21
PC2	.28	102.72	.03	3.33	103.08	.23	.32	102.66	.03	3.05	103.05	.21
PC3	.28	102.72	.08	3.33	102.98	.70	.32	102.66	.10	3.05	102.97	.65
PC4	.28	102.72	.06	3.33	102.91	.53	.32	102.66	.07	3.05	102.91	.48
6D2C	-.01	102.72	-.00	-.29	102.91	-.05	-.29	102.66	-.06	-.01	102.91	-.00
PC5	-.01	102.72	-.00	-.29	102.91	-.05	-.29	102.66	-.06	-.01	102.91	-.00
PC6	.27	102.72	.05	3.04	102.91	.48	.03	102.66	.00	3.04	102.91	.48
PC7	.27	102.72	.05	3.04	102.90	.48	.03	102.66	.00	3.04	102.90	.48
OK83	.27	102.72	.05	3.04	102.90	.48	.03	102.66	.00	'3.04	102.90	.48
PD1	.27	101.43	.02	3.04	102.10	.16				3.04	102.09	.16
PD2	.27	101.43	.10	3.04	102.08	.47				3.04	102.08	.47
PD3	.27	101.43	.07	3.04	102.00	.43				3.04	102.00	.43
PD4	.27	101.43	.09	3.04	101.97	.50				3.04	101.97	.50
PD5	.27	101.42	.06	3.04	101.89	.38				3.04	101.89	.38
PD6	.27	101.42	.09	3.04	101.85	.55				3.04	101.85	.55
PD7	.27	101.42	.07	3.04	101.79	.45				3.04	101.79	.45
PD8	.27	101.42	.09	3.04	101.76	.61				3.04	101.76	.61
9D1D	-.03	101.42	-.01	-.19	101.76	-.04				-.19	101.76	-.04
PD9	-.03	101.42	-.01	-.19	101.76	-.04				-.19	101.76	-.04
PD10	.24	101.42	.08	2.85	101.76	.57				2.85	101.76	.57
PD11	.24	101.41	.07	2.85	101.59	.65				2.85	101.59	.65
DKB4	.24	101.41	.07	2.85	101.59	.65				2.85	101.59	.65

contd.

Point	Case 1			Case 2			Case 3			Case 4		
	Disch-arge (m3/s)	Water level (m)	Velocity (m/s)	Disch-arge (m3/s)	Water level (m)	Velocity (m/s)	Disch-arge (m3/s)	Water level (m)	Velocity (m/s)	Disch-arge (m3/s)	Water level (m)	Velocity (m/s)
PE1	.24	100.05	.03	2.85	100.60	.19				2.85	100.60	.19
PE2	.24	100.04	.09	2.85	100.57	.54				2.85	100.57	.54
PE3	.24	100.04	.07	2.85	100.46	.45				2.85	100.46	.45
PE4	.24	100.04	.07	2.85	100.38	.51				2.85	100.38	.51
BRE1	.24	100.03	.06	2.85	100.28	.55				2.85	100.28	.55
PE5	.24	100.03	.06	2.85	100.28	.53				2.85	100.28	.53
PE6	.24	100.03	.06	2.85	100.26	.49				2.85	100.26	.49
6D3E	-.03	100.03	-.00	-.12	100.26	-.02				-.12	100.26	-.02
PE7	-.03	100.03	-.00	-.12	100.26	-.02				-.12	100.26	-.02
PE8	.21	100.03	.05	2.73	100.26	.47				2.73	100.26	.47
PE9	.21	100.03	.04	2.73	100.23	.46				2.13	100.23	.46
9D2E	-.00	100.03	.00	-.20	100.23	-.04				-.20	100.23	-.04
PE10	-.00	100.03	.00	-.20	100.23	-.03				-.20	100.23	-.03
PE11	.20	100.03	.04	2.53	100.23	.43				2.53	100.23	.43
PE12	.20	100.03	.05	2.53	100.21	.53				2.53	100.21	.53
DK85	.20	100.03	.05	2.53	100.21	.53				2.53	100.21	.53
PF1	.20	98.61	.03	2.53	99.22	.19				2.53	99.22	.19
PF2	.20	98.61	.10	2.53	99.21	.46				2.53	99.21	.46
DSF1	.20	98.61	.13	2.53	99.18	.60				2.53	99.18	.60
DSF2	.20	98.61	.13	2.53	99.18	.60				2.53	99.18	.60
DSF3	.20	97.11	.06	2.53	97.49	.48				2.53	97.49	.48
PF3	.20	97.11	.06	2.53	97.46	.46				2.53	37.46	.46
PF4	.20	97.11	.08	2.53	97.30	.70				2.53	97.30	.70
PF5	.20	97.11	.04	2.53	97.25	.45				2.53	91.25	.45
6D4F	-.01	97.11	-.00	-.15	97.25	-.03				-.15	97.25	-.03
PF6	-.01	97.11	-.00	-.15	97.25	-.03				-.15	97.25	-.03
PF7	.19	97.11	.04	2.38	97.25	.42				2.38	97.25	.42
PF8	.19	97.11	.04	2.38	97.25	.42				2.38	97.25	.42
9D3F	.00	97.11	.00	-.28	97.25	-.05				-.28	97.25	-.05
PF9	.00	91.11	.00	-.28	97.25	-.05				-.28	97.25	-.05
PF10	.19	97.11	.04	2.10	97.25	.37				2.10	97.25	.37
PF11	.19	97.11	.04	2.10	91.25	.38				2.10	97.25	.38
DX86	.19	97.11	.04	2.10	97.25	.38				2.10	97.25	.38
PG1	.19	94.61	.06	2.10	95.34	.18				2.10	95.34	.18
PG2	.19	94.61	.28	2.10	95.32	.63				2.10	95.32	.63
PG3	.19	94.38	.27	2.10	95.00	.55				2.10	95.08	.55
PG4	.19	94.24	.14	2.10	94.85	.61				2.10	94.85	.61
DSG1	.19	94.23	.12	2.10	94.75	.53				2.10	94.15	.53
DSG2	.19	94.23	.12	2.10	94.75	.53				2.10	94.75	.53
DSG3	.19	93.81	.06	2.10	94.57	.29				2.10	94.57	.29
PG5	.19	93.81	.08	2.10	94.54	.29				2.10	94.54	.29
PG6	.19	93.79	.12	2.10	94.48	.39				2.10	94.48	.39
8RG1	.19	93.77	.10	2.10	94.37	.41				2.10	94.37	.47
PG7	.19	93.77	.07	2.10	94.37	.29				2.10	94.37	.29
PG8	.19	93.75	.11	2.10	94.29	.45				2.10	'34.29	.45
PG9	.19	93.73	.09	2.10	93.95	.69				2.10	33.95	.69
PG10	.19	93.73	.03	2.10	93.92	.31				2.10	93.92	.31
6D5G	-.08	93.73	-.01	-.54	93.92	-.08				-.54	03.92	-.08
PG11	-.08	93.73	-.01	-.54	93.92	-.08				-.54	93.32	-.08

contd.

Point	Case 1			Case 2			Case 3			Case 4		
	Disch-arge (m3/s)	Water level (m)	Velocity (m/s)	Disch-arge (m3/s)	Water level (m)	Velocity (m/s)	Disch-arge (m3/s)	Water level (m)	Velocity (m/s)	Disch-arge (m3/s)	Water level (m)	Velocity (m/s)
PG12	.1	93.73	.02	1.56	93.92	.23				1.56	93.92	.23
P613	.1	93.13	.02	1.56	93.92	.23				1.56	93.92	.23
DK87	.1	93.73	.02	1.56	93.92	.23				1.56	93.92	.23
PH1	.1	93.04	.02	1.56	93.52	.14				1.56	93.52	.14
PH2	.1	93.04	.09	1.56	93.51	.38				1.56	93.51	.38
PH3	.1	93.03	.0P	1.56	93.40	.59				1.56	93.40	.59
PH4	.1	93.02	.06	1.56	93.33	.51				1.56	93.33	.51
PH5	.1	93.02	.03	1.56	93.18	.34				1.56	93.18	.34
9D4H	-.02	93.02	-.00	-.27	93.18	-.06				-.27	93.18	-.06
PH6	-.02	93.02	-.00	-.27	93.18	-.06				-.27	93.18	-.06
PH7	.09	93.02	.03	1.29	93.18	.28				1.29	93.18	.28
PH8	.09	93.02	.03	1.29	93.18	.28				1.29	93.18	.28
DKB8	.09	93.02	.03	1.29	93.18	.28				1.29	93.18	.28
PI1	.09	90.87	.02	1.29	91.58	.10				1.29	91.58	.10
BRI1	.09	90.87	.08	1.29	91.58	.37				1.29	91.58	.37
PI2	.09	90.85	.08	1.29	91.46	.34				1.29	91.46	.34
PI3	.09	90.83	.10	1.29	91.29	.46				1.29	91.29	.46
PI4	.09	90.82	.07	1.29	91.16	.39				1.29	91.16	.39
PI5	.09	90.82	.05	1.29	91.04	.49				1.29	91.04	.49
PI6	.09	90.81	.03	1.29	90.98	.30				1.29	90.98	.30
9051	-.05	90.81	-.01	-.28	90.98	-.06				-.28	90.98	-.06
PI7	-.05	90.81	-.01	-.28	90.98	-.06				-.28	90.98	-.06
PI8	.05	90.81	.01	1.02	90.98	.24				1.02	90.98	.24
PI9	.05	90.81	.01	1.02	90.98	.24				1.02	90.98	.24
DKB9	.05	90.81	.01	1.02	90.98	.24				1.02	90.98	.24
PJ1	.05	90.32	.02	1.02	90.98	.12				1.02	90.98	.12
PJ2	.05	90.32	.08	1.02	90.98	.26				1.02	90.98	.26
PJ3	.05	90.31	.06	1.02	90.95	.28				1.02	90.95	.28
PJ4	.05	90.24	.16	1.02	90.81	.43				1.02	90.81	.43
BRJ1	.05	90.21	.07	1.02	90.77	.40				1.02	90.77	.40
PJ5	.05	90.12	.11	1.02	90.65	.33				1.02	90.65	.33
PJ6	.05	90.11	.04	1.02	90.63	.34				1.02	90.63	.34
7D1J	-.03	90.11	-.03	-.21	90.63	-.07				-.21	90.63	-.07
PJ7	-.03	90.11	-.03	-.21	90.63	-.07				-.21	90.63	-.07
PJ8	.02	90.11	.01	.80	90.63	.27				.80	90.63	.27
PJ9	.02	90.11	.02	.80	90.60	.22				.80	90.60	.22
PJ10	.02	90.11	.02	.80	90.59	.23				.80	90.59	.23
PJ11	.02	90.11	.04	.80	90.50	.49				.80	90.50	.49
PJ12	.02	90.11	.00	.80	90.49	.19				.80	90.49	.19
7D2J	.00	90.11	.00	-.19	90.49	-.05				-.19	90.49	-.05
PJ13	.00	90.11	.00	-.19	90.49	-.05				-.19	90.49	-.05
PJ14	.02	90.11	.00	.61	90.49	.15				.61	90.49	.15
PJ15	.02	90.11	.00	.61	90.49	.15				.61	90.49	.15
7XXX	.00	90.11	.00	.00	90.49	.00				.00	90.49	.00
PJ16	.00	90.11	.00	.00	90.49	.00				.00	90.49	.00
PJ17	.02	90.11	.00	.61	90.49	.15				.61	90.49	.15
PJ18	.02	90.11	.00	.61	90.49	.15				.61	90.49	.15
PJ19	.02	90.11	.00	.61	90.49	.15				.61	90.49	.15

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