IIMI Working Paper 10

CALIBRATION OF THE KIRINDI OYA RBMC MATHEMATICAL FLOW SIMULATION MODEL:

DESCRIPTION OF THE FIELD MEASUREMENT CAMPAIGN AND PRELIMINARY RESULTS

Hilmy Sally, Daniel Berthery,
Frèderic Certain, and Andrè Durbec

INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE

IIMI's Working Paper series is intended to stimulate discussion among people interested in aspects of irrigation management. These papers make available the results of recent or on-going research, and the informed opinions of IIMI staff members and collaborators, as early as possible. The views expressed are therefore those of the authors, and do not (at this stage) necessarily represent the consensus of IIMI or its partners. IIMI will welcome comments on this paper, which should be sent either to IIMI or to the co-authors at the following addresses.

1) Hilmy Sally and Daniel Berthery
International Irrigation Management Institute
Digana Village via Kandy
Sri Lanka

TELEPHONE: (national 08; international 94-8) 74274, 74334, 74253
TELEX: 22318, 22907 IIMIHQ CE
FAX: (national 08; international 94-8) 32491

2) Fréderic Certain and André Durbec
CEMAGREF
3 Quai Chauveau
69336 Lyon Cedex 09
France

TELEPHONE: 78 83 49 48
TELEX: CMGREFL 305270 F

The authors Hilmy Sally and Daniel Berthery are, respectively, an Irrigation Management and Engineering Specialist and an Agricultural and Civil Engineer at the International Irrigation Management Institute (IIMI); Fréderic Certain and André Durbec are, respectively, an Agricultural Engineer and a Civil Engineer at the Centre National du Machinisme, Agricole du Génie Rural des Eaux et des Forêts (CEMAGREF), Lyon, France.

ACKNOWLEDGEMENTS

The development of the mathematical flow simulation model of the Kirindi Oya Right Bank Main Canal constitutes one component of the research activity conducted by IIMI in Sri Lanka on the interactions between the design and management of irrigation systems. This activity greatly benefited from the financial support granted to IIMI by the Government of France. CEMAGREF France, also made a significant financial contribution to the Simulation Model project itself. We gratefully acknowledge the support from both these sources.

We wish to thank the Chief Resident Engineer, the Senior Irrigation Engineer (Water Management) and the staff of the Kirindi Oya Irrigation and Settlement Project, Debarawewa for the cooperation extended during all phases of this research activity and particularly during the field measurement campaign.

The contribution of IIMI Research Assistants, Mr Asoka Hingurahena and Mr Jayantha Arumugam who participated in the collection and the analysis of field data, is also acknowledged.

CALIBRATION OF THE KIRINDI OYA RBMC MATHEMATICAL FLOW SIMULATION MODEL: DESCRIPTION OF THE FIELD MEASUREMENT CAMPAIGN AND PRELIMINARY RESULTS

INTRODUCTION

The International Irrigation Management Institute's (IIMI) current research on the operation of "Main Systems" is based on the hypothesis that control of the conveyance and primary distribution of water in main and branch canals could have a profound impact on efforts to improve management at lower levels. In fact an inflexible and unreliable primary water supply regime could negate many of the efforts exerted by irrigation agencies and farmers' organizations to achieve a reliable and equitable water supply below turnouts.

Analysis of current operational practices in the large canal networks of the rice-based irrigation systems in the humid tropics suggests that there is considerable potential for the development of effective and responsive main system management. Since operational practices are often conditioned by the particular design features for water level control in the main canal and discharge control at their offtakes, IIMI's research priorities in this area include analyzing the impact of design choices on the management and manageability of main canals.

Such research cannot be easily carried out in the field. Mathematical models that simulate the real system provide a convenient alternative to field research in investigating the behavior of irrigation canals under a variety of design/management scenarios without affecting normal canal operations. For example, such models could be used to assess the impact of any operational maneuver before actual intervention on the field.

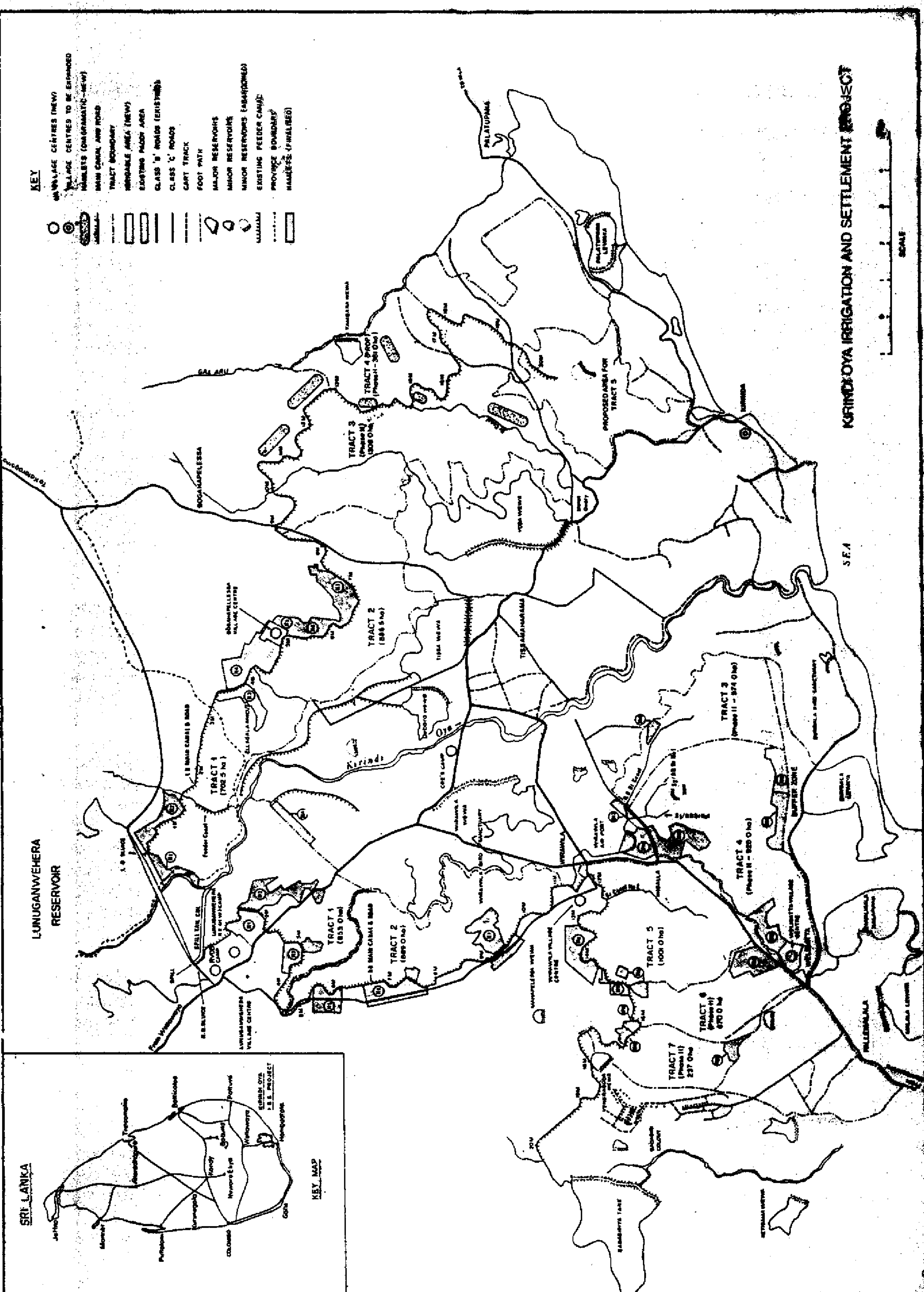
IIMI, in consultation with the Sri Lanka Irrigation Department, identified the Kirindi Oya Right Bank Main Canal (RBMC) as an appropriate site for a pilot application of a mathematical flow simulation model. For the implementation of this research project IIMI was able to secure financial assistance from the Government of France to supplement its own core funds, and associated itself with CEMAGREF (Centre National du Machinisme, Agricole du Génie Rural des Eaux et des Forêts), a public-sector applied research center in France which is providing additional expertise in computational hydraulics and computer technology.

The purpose of this paper is to document the field measurement campaign carried out in the Kirindi Oya RBMC with a view to calibrating the mathematical model. The preliminary analysis leading to estimates of some of the hydraulic parameters needed by the model is also described.

KIRINDI OYA RIGHT BANK MAIN CANAL (RBMC)

The Kirindi Oya Right Bank Main Canal (RBMC) is fed by the Lunugamvehera reservoir, located on the Kirindi Oya (river) in southern Sri Lanka (Figure 1) and having an active storage capacity of 198 million m^3. They were both

Figure 1. Kirindi Oya irrigation and settlement project.



constructed as part of the Kirindi Oya Irrigation and Settlement Project. This Project envisages the augmentation of irrigation water supplies for the existing irrigation system covering around 4500 hectares (ha), provision of irrigation facilities for an additional area of approximately 8400 ha together with the settlement of around 8320 families on the newly irrigated land. The implementation of the Project, planned in two phases, benefits from the financial assistance of the Asian Development Bank (ADB), Kreditanstalt fur Weideraufbau (KfW) and the International Fund for Agricultural Development (IFAD).

The RBMC is meant to irrigate approximately 5000 hectares of land. The development of a little over half this area was completed in mid-1986 under Phase I of the project. The Irrigation Department is in charge of managing the system, as well as the development of facilities under Phase II.

The RBMC is 32 kilometers (km) long and is designed to carry a discharge of 13 m^3/s at its head. The canal is unlined throughout its length and was designed with trapezoidal cross sections. The cross sections have however evolved over time into more irregular shapes primarily due to erosion and cattle damage. In addition, siltation has occurred in many places on the canal bed.

A total of 33 distributary and field canals take off directly from the RBMC. It is further characterized by the presence of 14 gated cross-regulators, of the undershot type, along its length. The coordinated operation of these regulators (each regulator having 2-5 manually operated sliding gates) is a key element in achieving effective control of water levels in the main canal, and hence of the primary distribution of discharges into the secondary and tertiary canals that take off from the RBMC. Ineffective operation of the control facilities could result in unreliable and inequitable water supply.

In the case of the RBMC, effective main canal operation becomes even more critical given that crop diversification is envisaged in the dry season (rice being the traditional wet-season crop), However, serious water shortages have so far prevented the satisfactory completion of two normal cultivation seasons in a year. This highlights the urgent need for improved management of the relatively scarce water resource, especially since the existing command area will be doubled after implementation of Phase II scheduled to commence in 1989.

In the context of this relatively water-scarce environment and its particular design features, it is hoped that the use of a mathematical flow simulation model of the Kirindi Oya RBMC would contribute to the identification of alternative management practices leading to improved distribution of water.

PRINCIPAL FEATURES OF THE MODEL

Model Structure

The core of the model is based upon well-established computer software developed by CEMAGREF in the field of open channel hydraulics and used by CEMAGREF for design and operation studies on rivers and canals. The software was originally designed to run on mainframe and mini-computers but later adapted to micro-computers.

The model is designed to run on an IBM-PC/AT (or compatible) micro-computer. It is made up of three software units that can be run either independently or sequentially. They are:

Unit 1: Topography Unit - This unit enables the user to input and verify all the topographic data pertaining to the canal. The software analyzes this data and generates specially coded files of geometric information that can be accessed for use by the other two units. A notable feature of this unit is that it can accommodate any type of canal cross section (regular or irregular), including single-bank canals.

Unit 2: Steady Flow Unit - This unit will calculate regulator and offtake gate openings as well as water surface profiles in the different canal reaches for any steady state scenario of water supply and demand. It also generates initial hydraulic conditions for activation of the Unsteady Flow Unit 3. An optional menu enables the user to impose or modify the hydraulic parameters of the canal (e.g., cross-regulator openings, canal losses, and roughness coefficients).

Unit 3: Unsteady Flow Unit - This unit simulates the unsteady flow conditions that prevail over certain periods of time in response to changes in water supply or demand, and modifications to gate settings. The user will be able to use this unit to assess the impact of different operational procedures (e.g., in terms of water losses or shortages, hydrographs at different points) to effect the transition from an initial steady state to a new one.

A major component of the Kirindi Oya RBMC flow simulation model project is the development of user-friendly conversational procedures so that the model could be used by non-specialized staff. The modular structure of the model will permit future modification or substitution of any of the hydraulic modules. For instance, the incorporation of a regulation module which would allow the inclusion of automatically adjustable control devices could be envisaged at a later stage,

Input Data Requirements

Since the model is a mathematical representation of the real system, it would only be as good as the quantity and quality of the information that is fed into it to describe the reality. The model should thus incorporate, as accurately as possible, all important physical and hydraulic features of the system.

The present model *is* limited to the first 25 km of the RBMC presently in operation. The input data, both physical and hydraulic, therefore only concern this stretch of main canal. However, the model can easily accommodate eventual *extensions* by modification of its topography unit.

The physical information was gathered in the course of a topographical survey. This included (a) the locations and descriptions of all cross-regulators, offtakes and other singularities on the =, (b) longitudinal profile of the *canal* bed, and (c) cross sections of the canal at appropriate intervals (100 meter intervals were used in the RBMC), trying as far as possible to capture all hydraulically significant features.

The hydraulic information required includes (a) roughness coefficients for the different reaches of the canal, (b) head-discharge relationships and discharge coefficients for the offtakes and regulators, and (c) seepage losses along the *canal.* Estimates of some of *these* parameters were obtained in the course of this measurement campaign.

FIELD MEASUREMENTS FOR MODEL CALIBRATION - STEADY FLOW

The measurement campaign was carried out, over a 10-day period in April-May 1988, by a joint IIMI-CEMAGREF team with the assistance *of the* Irrigation Department. In carrying out all observations and measurements a primary concern was to cause minimum disruption to normal irrigation activities in the RBMC project area.

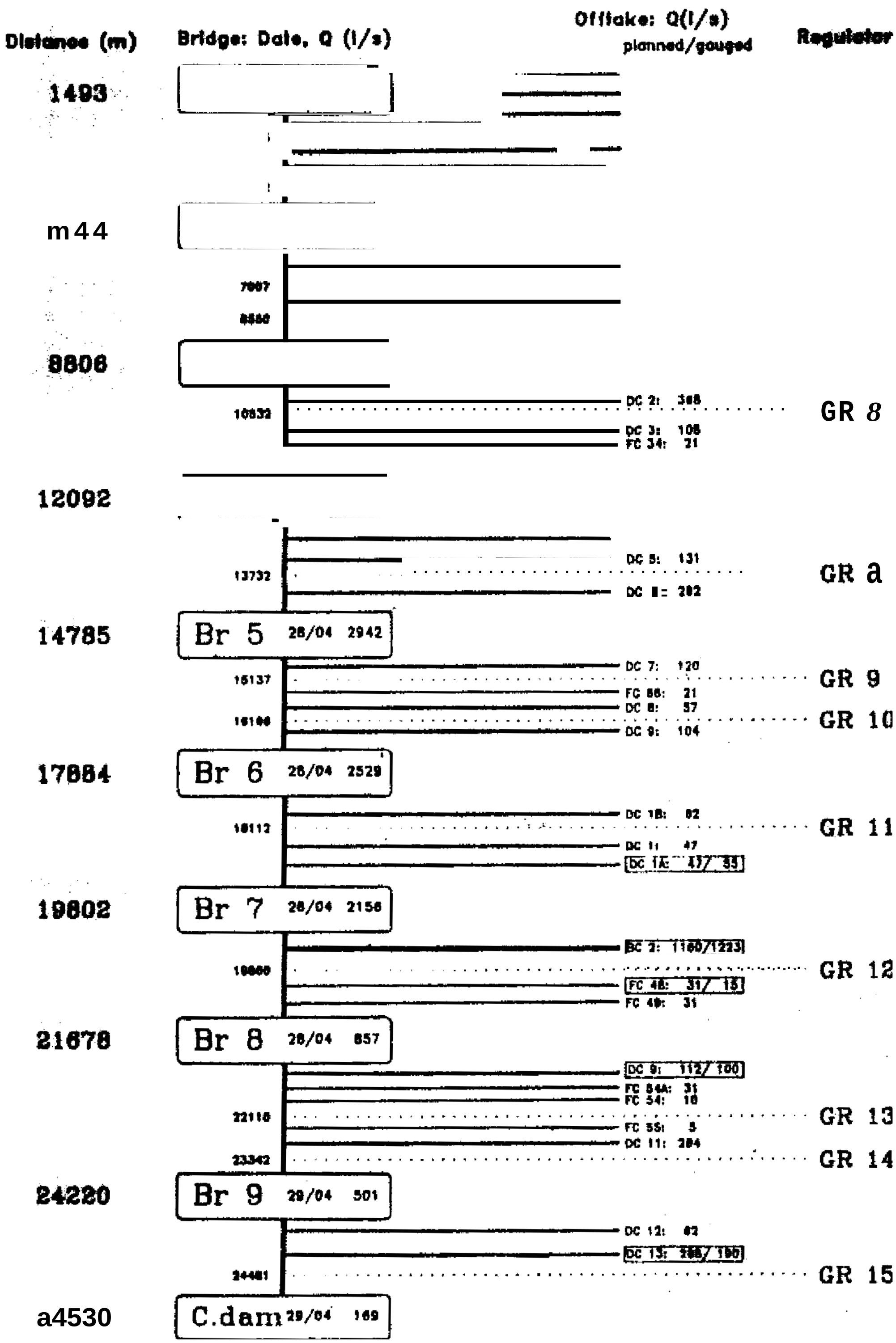
Water Surface Elevation and Discharge Measurements

In this phase of the calibration, which was the most time-consuming, an inventory of the status of the RBMC system under given steady conditions of canal water flow and gate settings was taken. The Irrigation Department had undertaken not to alter the main canal *discharge* nor the gate settings until the end of the calibration campaign. Marks were painted *on* the gate spindles so that it would be possible to ascertain at a glance if *any* of these gate *settings* had been altered.

Water surface profiles in the main canal were computed by measuring water levels *at* all offtakes, and upstream and downstream of each cross regulator (denoted GR2 to GR15) with respect to temporary bench marks (TBM) of known elevations established at these locations.

The discharges at different points in the RBMC as well as at sane offtakes were estimated using an OTT-C31 currentmeter. *Gauging* in the main canal was performed from 9 different bridges and at the heads of sane *canals* taking off from the main *canal.* These gauging points are *shown* enclosed in boxes in Figure 2 and are located at the distances indicated. The measured discharges are indicated in upright characters while the figures in italics refer to the Irrigation Department's planned discharges for the period in question.

Figure 2. Gauging locations.



The openings of all regulator and offtake gates were computed via observations of their respective spindle heights; the relations between gate openings and spindle heights had been established earlier for *each* gate. Figure 3 describes the state of the different offtakes of the RBMC during the calibration campaign, The indication eps (for epsilon) is used to denote an offtake which was for all intents and purposes closed but through which a very small flaw nevertheless escaped.

Figure 4 summarizes the information contained in Figures 2 and 3, and indicates the discharge values finally chosen for the steady flaw calibration of the RBMC model.

Canal Losses

The discharge values indicated in Figure 4 are also used to compute seepage and percolation losses in each gauged reach of the RBMC. It is assumed that the losses are uniformly distributed over the entire reach. Wherever the offtake has been gauged, the measured discharges are taken intc account in the computation. Otherwise it is assumed that the targeted discharge is being delivered at the offtake.

Consider a typical reach 1-2 with n *offtakes:*

```
|==========|========|=================|==========|==>
           |        |                 |
Q1         q1       q2      . . .     qn         Q2
```

$$\text{Loss} = \frac{(Q_1 - q_1 - q_2 - \ldots - q_n - Q_2)}{x_2 - x_1}$$

where Q_1, Q_2 = Discharge at upstream and downstream ends of reach 1-2
x_1, x_2 = Relative distances of upstream and downstream *ends*
$q_1, \ldots$ = Discharge at offtakes 1,...

The losses were computed according to the above method for the different *canal* reaches bounded by the bridges where gauging was performed. The results for *all peaches,* except the last two, are *given* in Table 1. In reach Br 8-Br 9 the sum of the outflows is greater than the inflow, possibly indicating that the target discharge in DC11 (distributary channel no.11) remains unsatisfied. *On* the other hand, unusually high losses seem to occur in reach Br 9-COFDAM which could mean that the *actual* discharge in DC12 *exceeds* the target value.

Figure 3. State of the offtakes during the calibration.

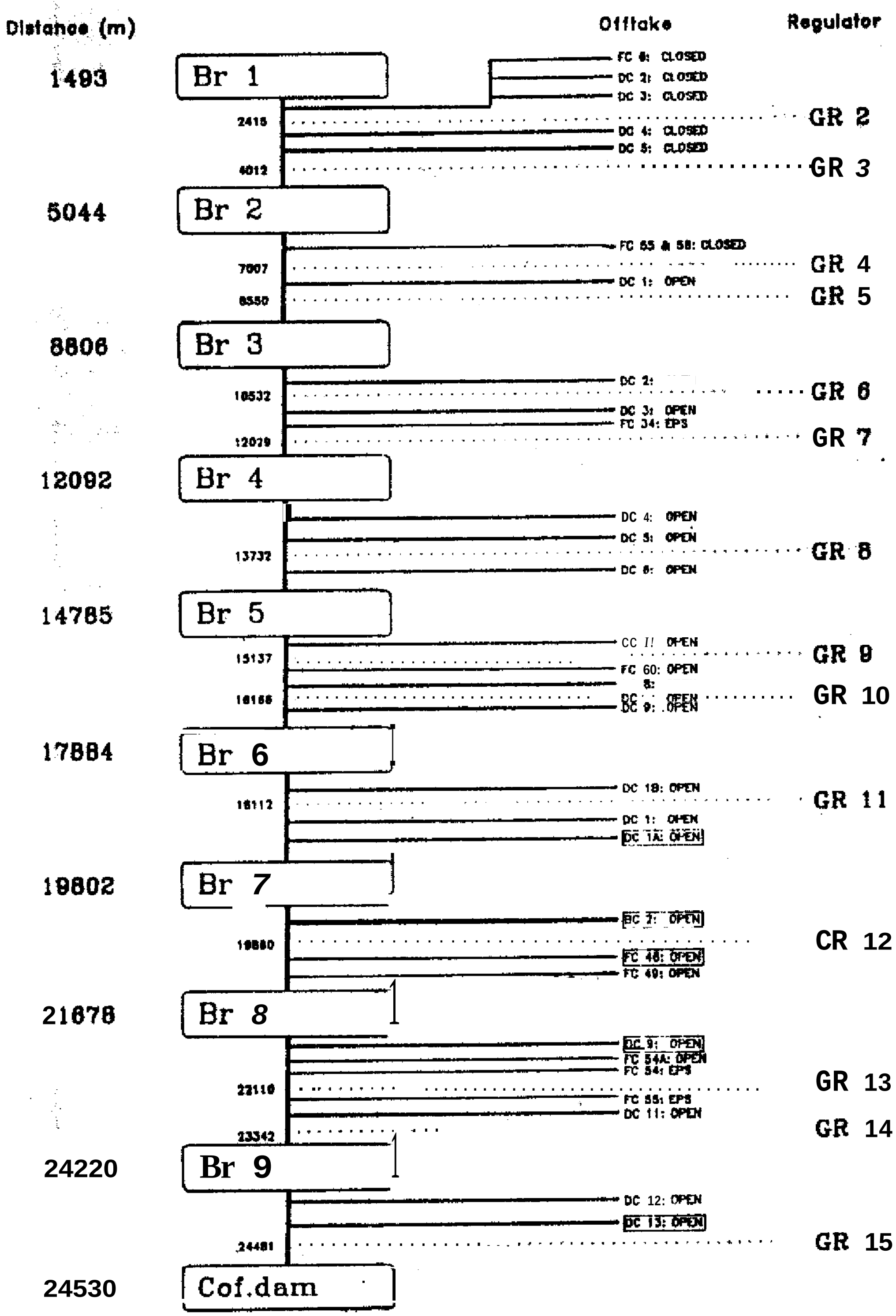


Figure 4. **Adopted discharge** values.

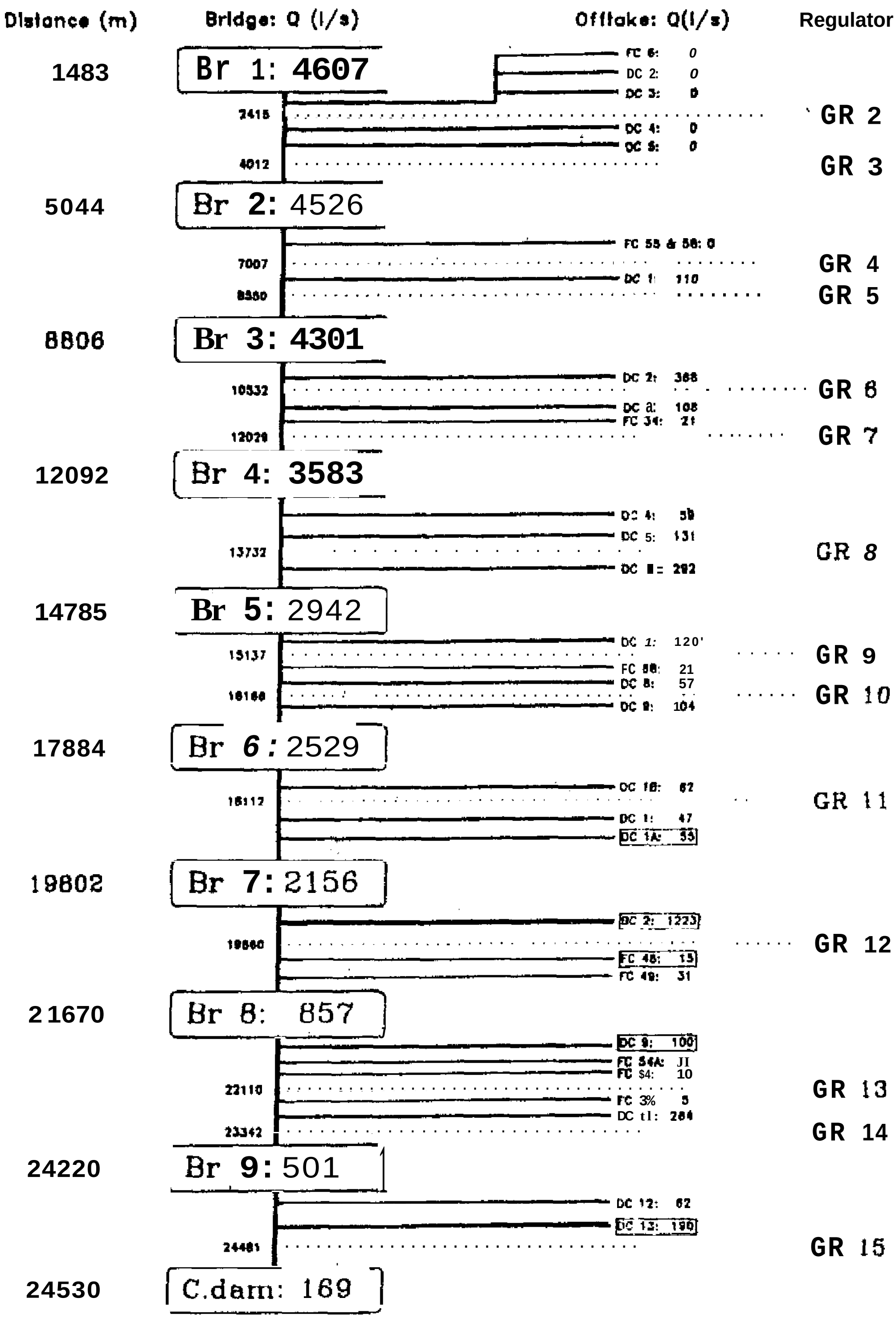


Table 1. Computation of Canal Losses

Bridge	Q(l/s)	Relative Distance (m)	Discharge (l/s)	Length (m)	Mean losses (l/s/m)
Br 1	4 607	1 493			
			} 0	3 551	0.023
Br 2	4 526	5 044			
			DC1 110	3 762	0,031
Br 3	4 301	8 806			
			DC2 368 DC3 108 FC 34 21	3 286	0.067
Br 4	3 583	12 092			
			DC4 59 DC5 131 DC6 292	2 693	0.059
Br 5	2 942	14 785			
			DC7 120 FC 68 21 DC 8 57 DC 9 104	3 059	0.036
Br 6	2 529	17 844			
			DCI B 62 DCI 47 DCIA 55	1 958	0.107
Br 7	2 156	19 802			
			BC 2 1223 FC 48 15 FC 49 31	1 876	0.016
Br 8	857	21 678			
			DC 9 100 FC54A 31 FC 54 10 FC 55 5 DC 11 264	2 542	aberrant DC11 targetted discharge might be unsatisfied.
Br 9	501	24 220			
			DC 12 62 DC 13 190	310	aberrant DC11 targetted discharge might be exceeded.
COP-DAM	169	24 530			

It will be observed that there is a wide range of variation in the losses obtained for the different reaches. This reflects the variation in construction of the different canal sections, i.e., whether it is built entirely below the natural terrain ("cut"), entirely above the natural terrain ("fill"), *or* partly in "cut" and "fill". The losses would be least in the first situation while greatest in the second. Figure 5 gives a description of the nature of the different canal sections of the RBMC.

The weighted mean value for RBMC losses, taking into account the values obtained between Br 1 to Br 8, *is* 0.046 l/s/m (or 2.44 cusecs/mile).

This is equivalent to a loss *of* 1.13 m^3/s (or 40 cusecs) over the 25 km of canal from the headworks to the cross-regulator GR15, which corresponds to the length' of canal presently considered in the simulation model. This also corresponds to a loss of approximately 25 percent with respect to the discharge *of* 4.607 m^3/s measured at the head of the main canal.

To conclude this section, we would like to emphasize that the loss values obtained at this stage are only approximate, But they nevertheless give some indication of canal losses in a situation where there was hardly any information available previously, The approximate nature of these results is due to the uncertain offtake discharges; the discharges q_1 , q_2 , ... etc., were not directly measured at all the offtakes. In the computation of losses it was assumed that the ungauged offtakes were delivering flows equal to their respective targets. This is perhaps not always true, as evidenced by the unusual results obtained in reaches Br 8-Br 9 and Br 9-COFDAM. More reliable estimates of canal losses would have been obtained if discharge measurements had been performed at all the offtakes, or *if* all the offtakes had been closed, It is planned to carry out measurements under the latter conditions (i.e., flow only in the main canal with all offtakes closed) sometime towards the end of the present cultivation season.

Estimation of Roughness Coefficient

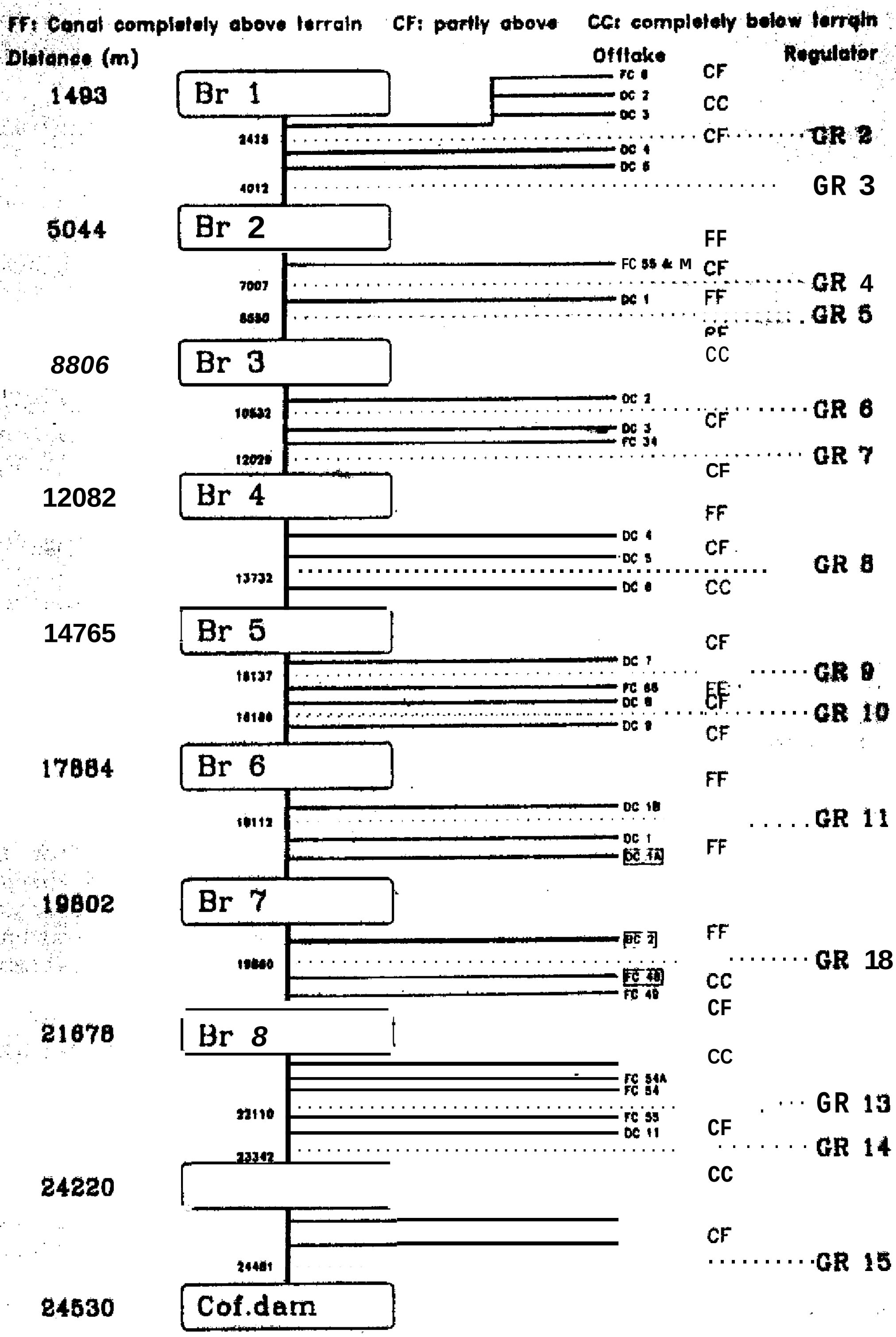
The roughness coefficient is an indicator of the resistance offered by the canal to *the* flow *of* water. It could display both spatial and temporal variations since the canal condition itself could vary at different points of the canal and could evolve over time (e.g., weed growth). The roughness coefficient (in the form of the Strickler coefficient) is an essential model parameter used in the computation of the friction gradient.

The standard Manning-Strickler equation for open-channel flow *can* be represented as:

$$Q = K.A.R^{2/3}.i^{1/2} \quad \text{---------------} \quad (1)$$

where
- Q = Discharge
- K = Strickler coefficient (= 1/Manning's n value)
- A = Cross section of flow
- R = Hydraulic Radius = A/P, with P = wetted perimeter
- i = Bed slope (=0.0003)

Figure 5. Kirindi Oya RBMC: Nature of canal sections.



This equation is only valid for uniform *flow,* which does not usually prevail in irrigation main canals. This is due to the backwater effects caused by downstream regulating structures. In fact, in the Kirindi Oya RBMC most regulators are located in the backwater curve of the regulator immediately downstream.

In the field however, for the purpose of carrying out immediate unsteady flow simulations, the Manning-Strickler equation was used to obtain friction coefficient values at the gauged sections. Only the results obtained at the first four bridges (Br 1 to Br 4) were conserved as the other bridges were obviously influenced by downstream regulators at the time of measurement. The results are indicated in Table 2.

Table 2. Estimation of roughness coefficients.

Location	Q (l/s)	A (m^2)	$R^{2/3}$	Strickler K	Manning n
Br 1	4607	12.75	0.968	22	0.045
Br 2	4526	11.28	0.913	25.4	0.039
Br 3	4301	11.50	0.945	22.9	0.044
Br 4	3583	10.91	0.913	20.8	0.048

The above values *of* Roughness Coefficients were only preliminary estimates used to plan the field measurements under unsteady flow conditions (see below).

The final values to be adopted in the simulation model were obtained upon the completion of the calibration computations. This involved adjusting the value of the roughness coefficient for the different reaches by a manual iterative method until there was reasonable agreement between the computed and observed water surface elevations, whilst at the same time ensuring that there was conservation *of* the volumes of water being conveyed in the different canal reaches.

The final Strickler roughness coefficients obtained are between 25 and 35. *These* are less than the value of 40 assumed at the design stage. This implies that the canal roughness is higher than what was originally assumed, leading to a proportional reduction in canal carrying capacity.

Calibration of Cross Regulator

The calibration was carried out at cross regulator CR3, where IIMI had installed automatic data-logging equipment to continuously monitor water levels in the RBMC and in the nearby DC5 distributary *canal.* The object of the calibration was to determine an appropriate coefficient of discharge for

the regulator gates. The value obtained will be considered to be representative fur all the regulators.

GR3 is a 5-bay regulator (Figure 6). For a given combination of gate settings, measurements of water levels upstream and downstream of the cross regulator were made with respect to the top of the side check walls (corresponding to the Full Supply Depth -- FSD). The spindle heights were also noted, from which the relevant gate could be derived. Adjustments to gate settings were made such that, as far as possible, the same opening was maintained at each of them. It was, however, not possible to make adjustments to one of the gates which remained blocked.

Since all offtakes upstream of this regulator were closed during the measurement campaign, the main canal discharge was not affected by changes to gate settings. It was *only* possible to conduct this experiment for one value of steady discharge during this present field measurement campaign. However, measurements corresponding to five different gate settings were made for this particular discharge. It is hoped to repeat this operation for at least two other steady state discharge conditions.

This particular experiment was performed on 26 April 1988 when the main canal discharge was 4.475 m^3/s. The different gate openings effected that day, expressed in terms of area of opening, are shown in Figure 7.

Measurements were undertaken only after allowing time for the upstream water level to regain stability following a gate adjustment. Although over two hours had elapsed between successive sets of gate adjustments, examination of the water levels recorded by the data logger upstream and downstream of the regulator GR3 that day (Figure 8) indicates that complete stability had in fact not been attained at the end of each set of adjustments. This clearly demonstrates the wealth of useful information that can be obtained from the continuous data logger records.

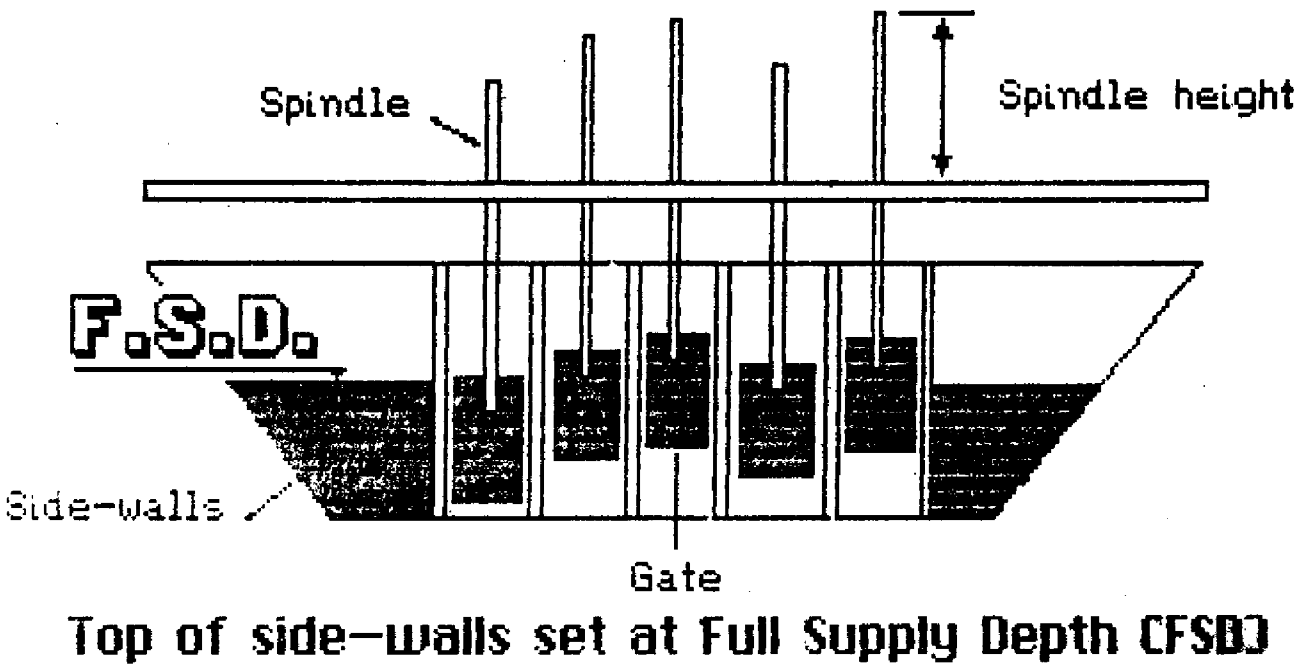
The flow actually *passing* through the regulator gate openings was estimated by subtracting the flow over the side check walls and over any of the gates themselves (wherever applicable) from this value (Figures 9 and 10). The classic equation for free flow over a weir was used with a discharge coefficient of 0.36 to compute these overflows:

$$Q_w = 0.36L\ (2g)^{1/2}\ H^{3/2} \quad \text{----------------(2)}$$

where Q_w = Discharge over the weir (side check-walls or gates themselves in this case)

- L = Length of weir
- H = Head over weir
- g = Acceleration due to gravity

Figure 6. Schematic *diagram* of a 5-bay cross-regulator,



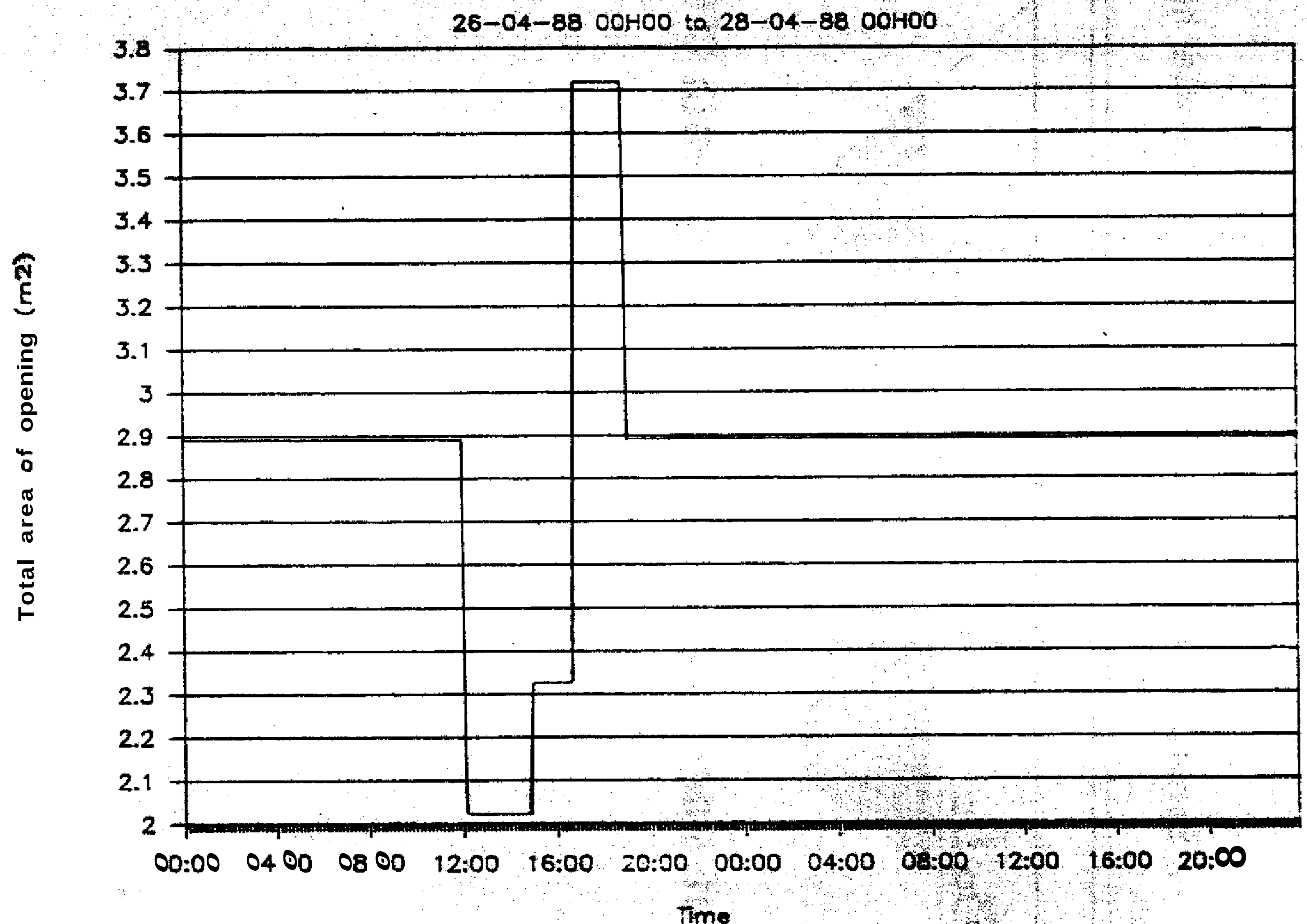


Figure 7. Cross-regulator CR3 - gate openings.

Figure 8. GR3 - levels upstream and downstream.

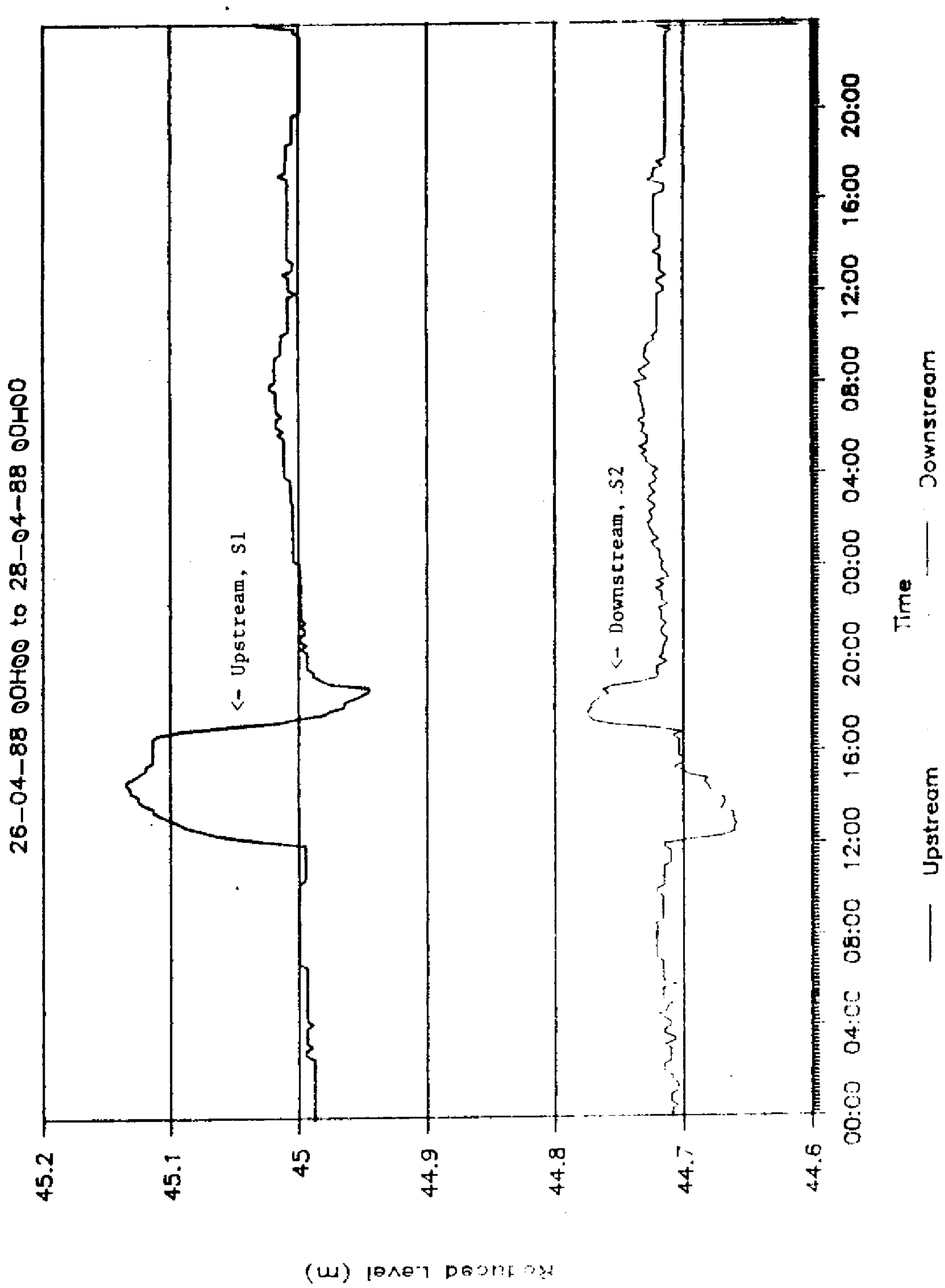


Figure 9. GR3 - heads: total and over sidewalls.

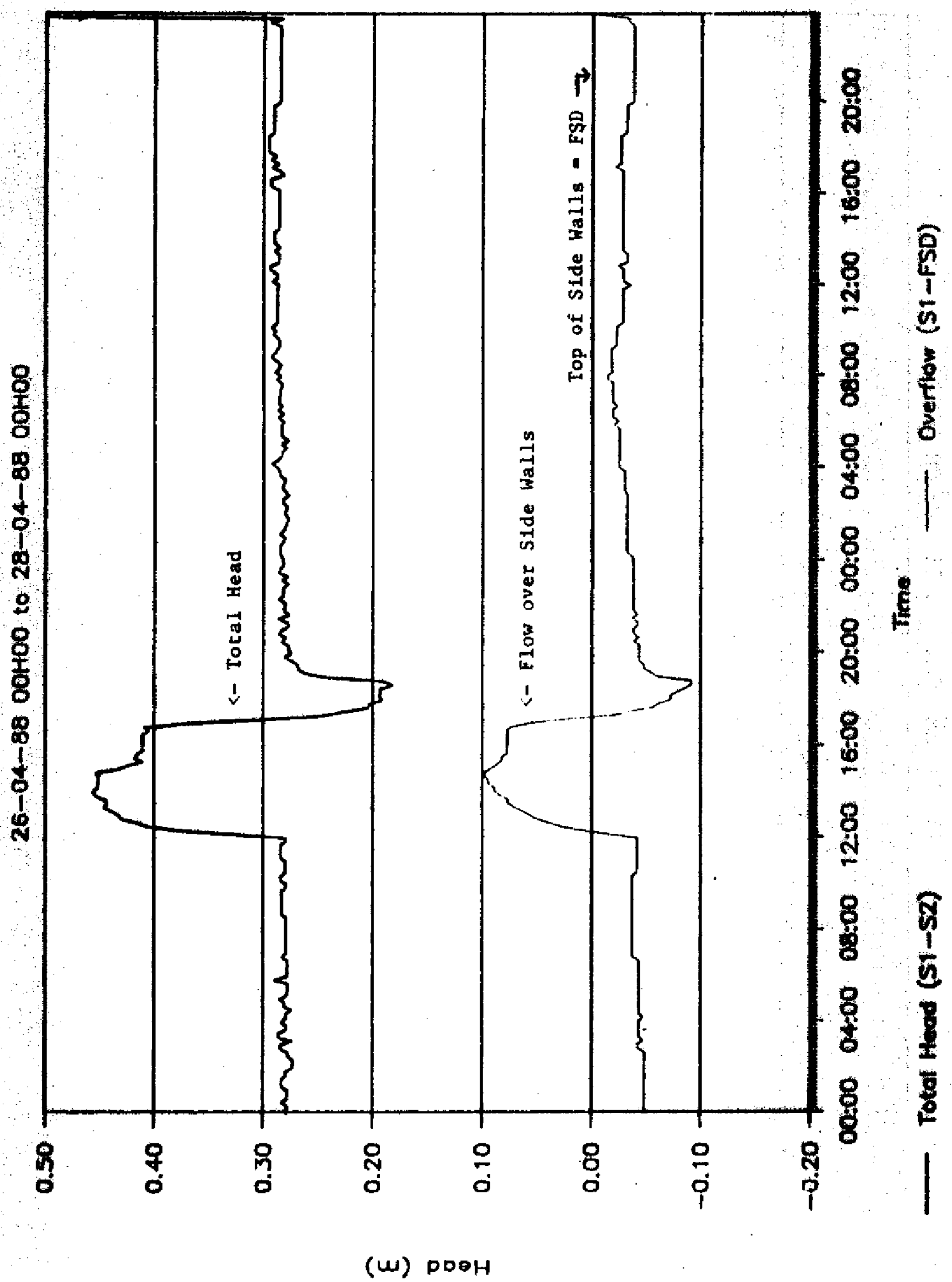
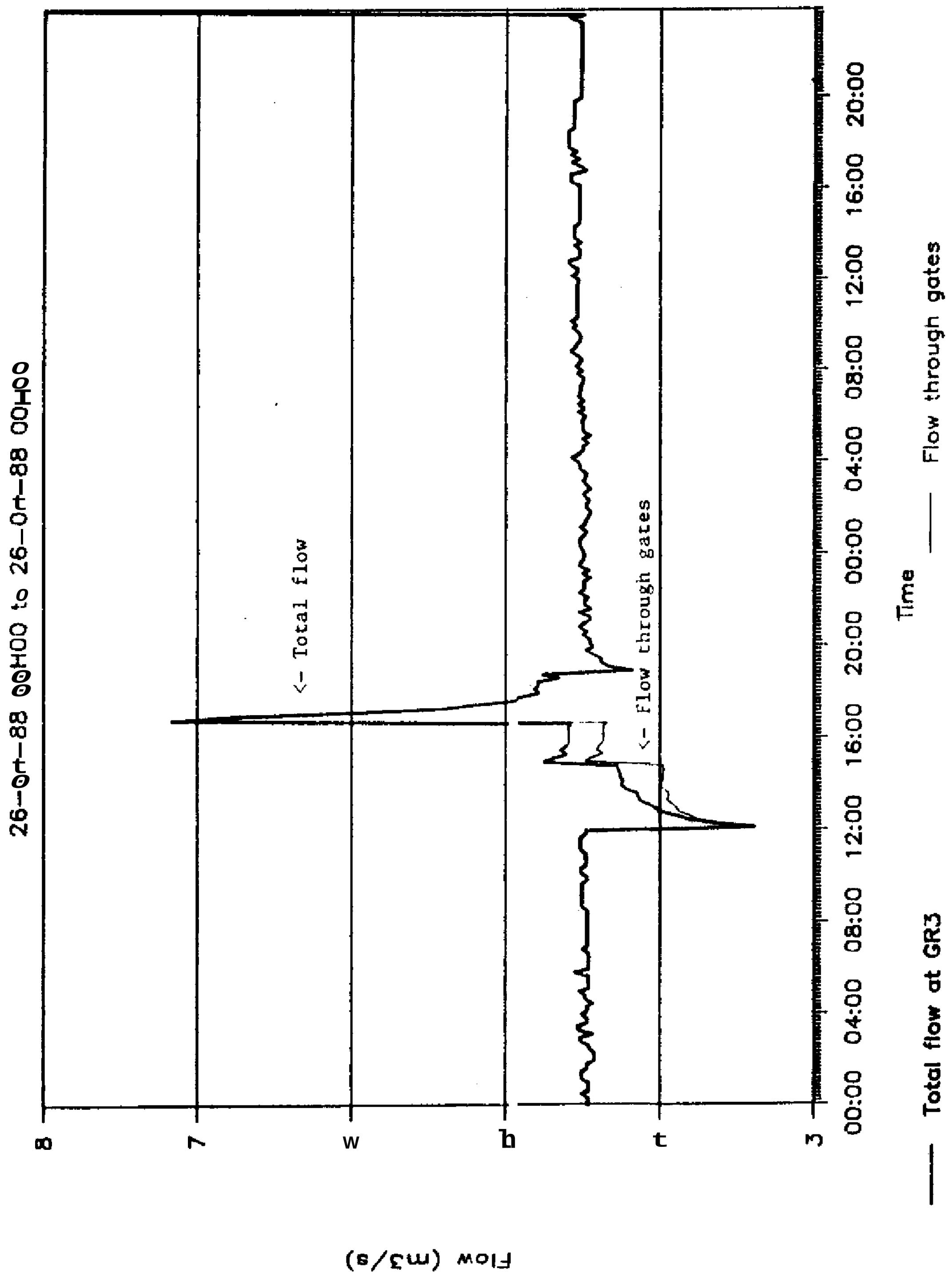


Figure 10. GR3 - flows.



The flow through the cross-regulator gates, denoted by Q_g, is then given by:

$$Q_g = Q_m - Q_w \quad \text{------------------(3)}$$

where Q_m is the observed main canal discharge at the time of the experiment.

The following equation was used for discharge through the cross-regulator gates:

$$Q_g = C_d . A. [2g(S_1 - S_2)]^{1/2} \quad \text{------------------(4)}$$

where
Q_g = Discharge through the regulator gates
C_d = Coefficient of discharge
A = Total area of flow through gates
S_1 = Water level upstream of regulator
S_2 = Water level downstream of regulator
g = Acceleration due to gravity

All quantities in equation (4) are known (or measured) except for the coefficient of discharge C_d, which can thus be calculated.

The values of C_d obtained at the end of each set of gate adjustments are as follows:

Test 1, C_d=0.659; Test 2, C_d=0.695; Test 3, C_d=0.648;
Test 4, C_d=0.620; Test 5, C_d=0.657.

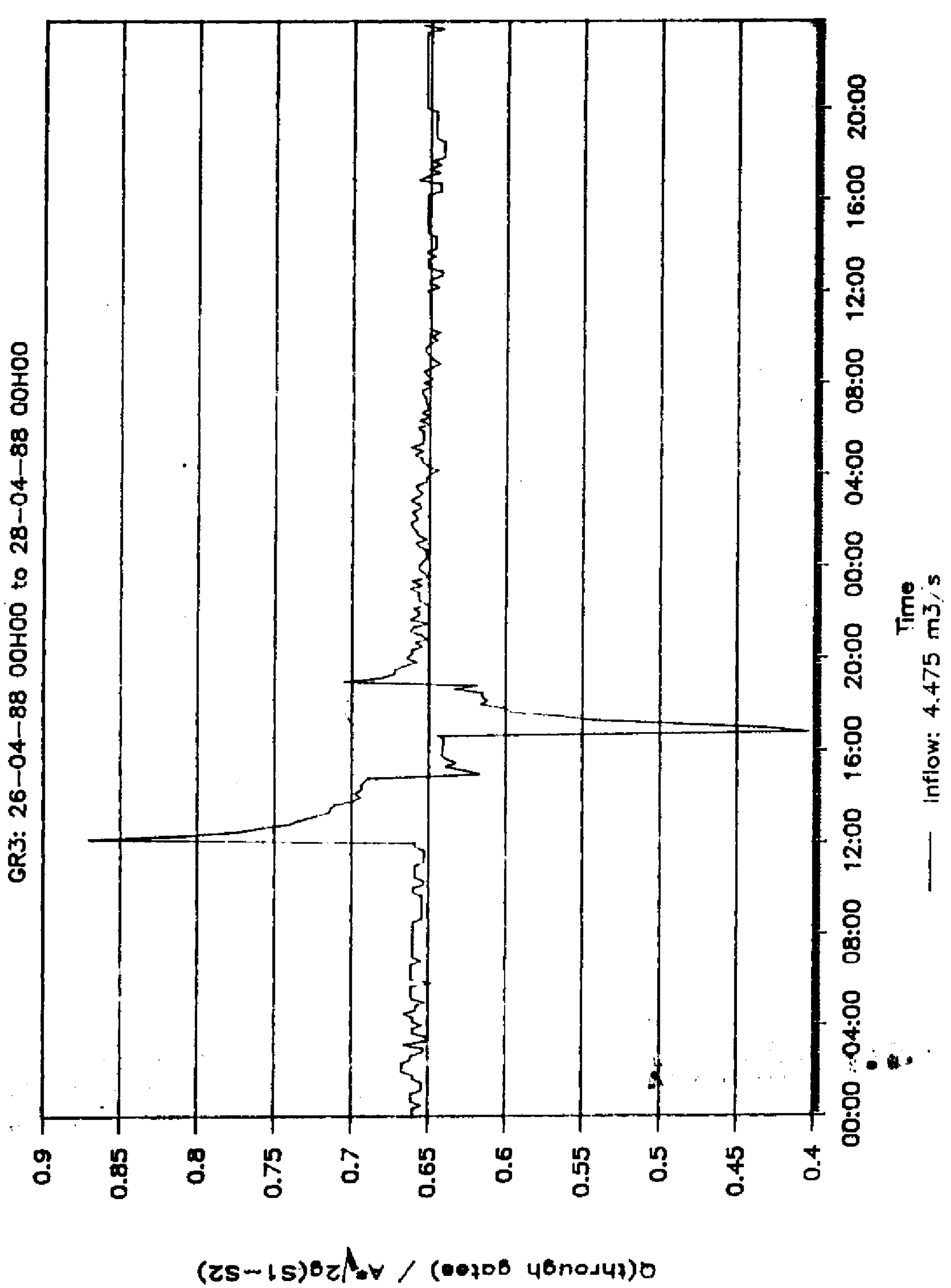
The range of different values obtained is perhaps due to the fact that fully stable conditions were not prevalent at the time of measurement. Figure 11 shows the different values of C_d obtained for the whole record from 26 to 28 April. It would appear that the most persistent value of C_d for this period is around 0.66.

FIELD MEASUREMENTS FOR MODEL CALIBRATION - UNSTEADY FLOW

The main purpose of this operation was to monitor the propagation along the RBMC of a wave generated by a sudden additional discharge at the head of the canal. The magnitude of this additional discharge was determined by trial runs of the simulation model (both steady and unsteady state) on the IBM-PC/AT micro-computer of the Kirindi Oya Irrigation and Settlement Project. A Strickler coefficient value of 25 was assumed throughout the length of the RBMC. The initial conditions for the unsteady flow simulations corresponded to the state of the system (water surface elevations, discharges etc.) obtained during a steady flow simulation.

The choice of the magnitude and duration of the additional release to be made at the headworks was a compromise between (a) considerations of safety

Figure 11. Computation of discharge coefficient.



which required that the flow should not be so great that the RBMC would overflow its banks at some point, and (b) the need to generate a wave that would not attenuate too soon thereby making it difficult to monitor its arrival and progress especially towards the tail of the canal. It was finally decided that an extra release of about 1.5 m^3/s over 3 hours would be suitable.

At 06:30 on 2 May 1988 this additional release was made at the Lunugamvehera Reservoir headworks. Water level variations were recorded every 10 minutes upstream and downstream of the side check-wall of every cross-regulator. These tasks were performed by 15 students from a local school each of whom was equipped with a watch, ruler, and record-book.

The variations in water levels recorded by the data-logger at the cross-regulators GR3 and GR12 (upstream and downstream of the cross-regulator) in response to this additional release are illustrated in Figure 12. This plot indicates that the wave first arrived at the GR3 location around 07:00 (or half an hour after it was released at the headworks), and that the peak arrived at about 09:40.

At the same time the RBMC discharge was gauged from time to time at the Br 1 location. The gauging results were as follows:

Table 3. RBMC discharge measurements during unsteady flow calibration phase.

Time	Discharge (liters/s)
Initial Value	4607 (Steady flow value)
0723	5831
0745	5765
0915	6159 (New steady flow regime)

The main sluice was returned to its original position at 0940. The supplementary discharge measured was 1.552 m^3/s.

The water level observations at the cross-regulators continued until the new steady flow regime was established at each location. This occurred progressively at each regulator from upstream to downstream.

Interpretation of the observations was however rendered difficult by the cleaning of the protective grill at the upstream end of the siphon located at a distance of approximately 7 km. Weeds and other debris had been deposited against this grill overnight, causing an accumulation of water in the canal

Figure 12. Water levels at GR3 and GR12 on 2 May 1988.
(Water released at 06:30H from the dam)

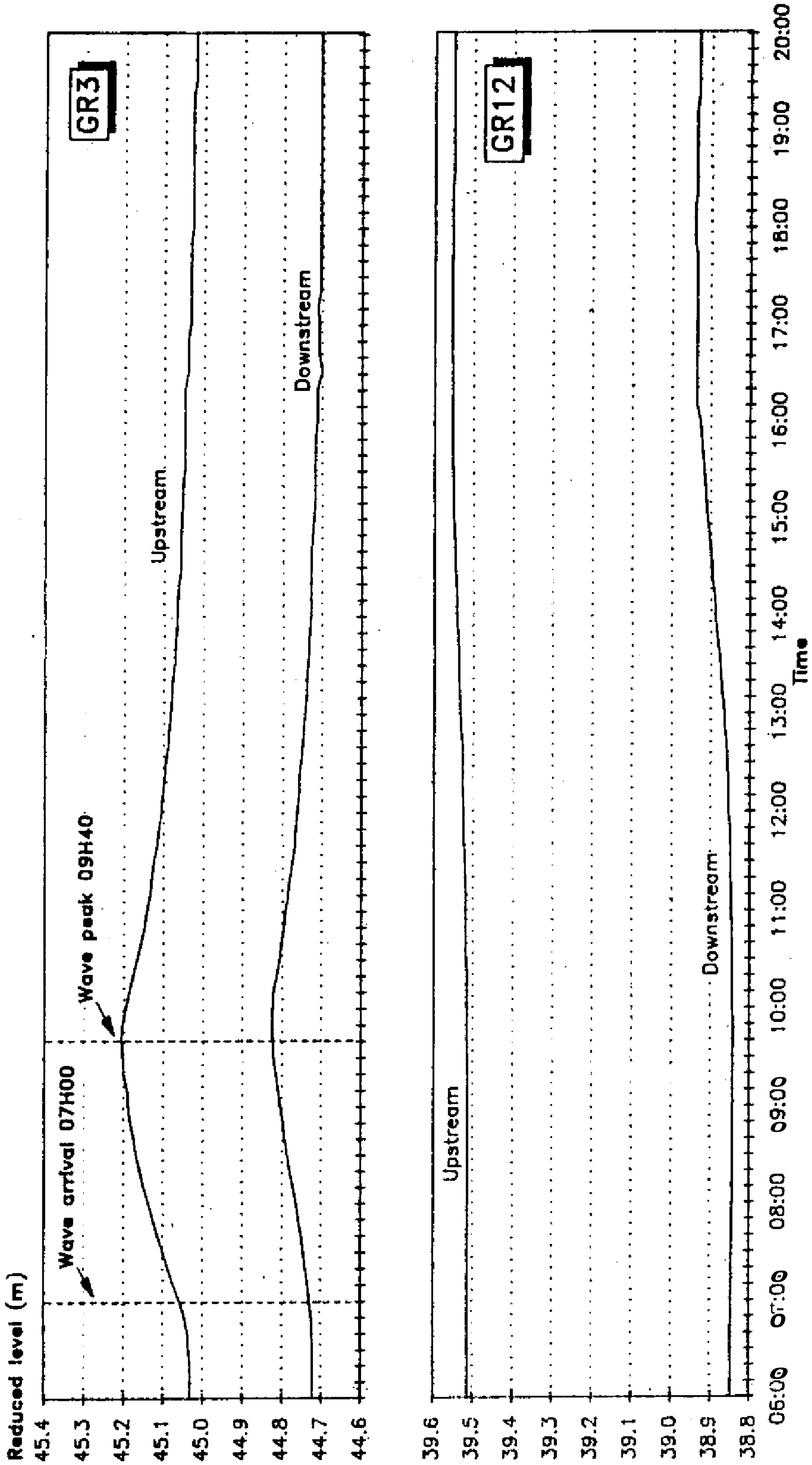


Figure 13. Results of unsteady flow calibration.

Time of arrival of the wave:

Figures in brackets are doubtful data

Distance (m)	Structure / station (m)	arrival of wave HH:MM	mean velocity km/h	arrival of maxi HH:MM	mean velocity km/h	Device
1493	Br 1					
	2418	0:20	7.3	3:10	0.7	GR 2
	4012	0:30	8.2	3:30	1.2	GR 3
5044	Br 2					
	7007	2:00	3.5	4:30	1.5	GR 4
	7387	2:00	3.7	4:40	1.6	Syphon
	8550	2:20	3.7	5:00	1.7	GR 5
8806	Br 3					
	10832	3:30	3.0	5:30	1.9	GR 6
	12029	3:40	3.3	6:40	1.8	GR 7
12092	Br 4					
	13732	(5:10)	(2.6)	7:10	1.9	GR 8
14785	Br 5					
	15137	?		8:00	1.9	GR 9
	16166	?		9:00	1.8	GR 10
17884	Br 6					
	18112	(6:50)	(2.7)	9:30	1.9	GR 11
19802	Br 7					
	19880	(6:50)	(2.0)	(11:00)	(1.8)	GR 12
21678	Br 8					
	22110	(7:40)	(2.9)	(12.90)	(1.8)	GR 13
	23342	(8:00)	(2.9)	>12:00		GR 14
24220	Br 9					
	24481	(10:40)	23	>12:00		GR 15
24530	Cof.dam	averages 3 km/h or 1.9 mile/h		1.8 km/h or 1.1 mile/h		

reaches upstream of this location. *Their* removal (which took place between 07:30 and 08:30) provoked a sudden release of this stored water resulting in the propagation of another positive wave downstream of the siphon (and possibly a negative wave upstream of it).

The estimated times of arrival of the wave and its peak are *given* in Figure 13. The average velocity of wave propagation was around 3 km/h (1.9 mile/h), whereas the peak of the wave was propagated at a velocity of 1.8 km/h (1.1 mile/h). *Such* values are useful for design purposes and for estimation of response times.

CONCLUSIONS AND FUTURE DEVELOPMENTS

The field measurement campaign was an essential step in the development and exploitation of the Kirindi Oya RBMC mathematical *flow* simulation model. In order that it yield reliable and useful results the model should accurately reflect the *physical* and hydraulic features of the canal, The field measurements contribute to matching the model behavior to actually observed situations. The staff of the irrigation *agency* would then be able to recognize the model as *truly* representing "their" *canal.*

The cooperation and active participation of the Irrigation Department project staff in different phases of the field measurements largely contributed to the success of this campaign. They were particularly interested in using the model to estimate maximum conveyance capacities and identify potential bottlenecks to the smooth operation of the RBMC (e.g., the siphon grill and points *of* insufficient freeboard). Though not yet fully calibrated, the model did yield some indicative results in this direction.

Once fully calibrated IIMI intends using the model as a research tool to further its objectives in the field of design and management interactions. The Kirindi Oya RBMC model will be used as a test *case* to demonstrate the potential of the mathematical simulation model in investigating innovative main canal design and management practices. Different canal regulation technologies and design concepts *can* be evaluated without having to incur expenditure on actual field installation *or* testing. It is hoped that the dissemination of *the* results of this case study will generate sufficient interest amongst other agencies to *employ* similar methodologies *in* their own work.

The model also offers a training tool €or system managers to familiarize themselves with the behavior of *the* main canal in response to a variety of design and management scenarios. This is especially useful if the canal has been recently commissioned, or in the event of a change in system operators.

IIMI, in collaboration with the Irrigation Department, *can* use the model to identify and test practical procedures for improved manual operation of the main *canal.* The development *of* user-friendly input and output interfaces, now underway, will facilitate model use and interpretation of results. This collaborative relationship could be extended to the implementation and monitoring of such operational procedures.