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WATER MANAGEMENT IN A TANK CASCADE IRRIGATION SYSTEM IN SRI LANKA

First Seasonal Report of TARC-IIMI Joint Project
1991/1992 Maha Season

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and
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IIMI

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INTRODUCTION

THE INTERNATIONAL IRRIGATION Management Institute (IIMI) and the Tropical Agriculture Research Center (TARC), Ministry of Agriculture, Forestry and Fisheries of Japan, initiated a collaborative study in August 1991. This joint study is focussed on small-scale tank irrigation systems which are spread over the Dry Zone of Sri Lanka, and is conducted with the assistance of Sri Lanka's Department of Agrarian Services.

In Sri Lanka, what are called "tank cascade irrigation systems" have developed as ultimate stock-type irrigation systems. These systems are interconnected storage and regulating reservoirs which serve multiple functions of resource management including irrigation, domestic water supply, water for livestock and subsurface water supply for perennial cropping. Some of these tanks have very long histories which date back over a thousand years, and were once the backbone of an ancient hydraulic civilization which flourished in the north and central part of the country. From about the 12th century A.D. a series of events led to the decline of the ancient civilization and movement of population to the Wet Zone further south. Major part of the Dry Zone and the ancient irrigation systems lay abandoned until about the early stages of the present century when sporadic attempts were made to restore some of these systems, but initially most of the efforts were focussed on the larger irrigation systems. More recently, large sums of money have been invested both by various international donor agencies and by the Government of Sri Lanka to rehabilitate small-scale irrigation systems as a key component of the Sri Lankan Government's agricultural development policy.

The principal objective of the IIMI/TARC Joint Project is to carry out research for improving irrigation management in the tank cascade irrigation systems in small watersheds. Unlike most previous studies on small tank irrigation systems in Sri Lanka which consider each tank as a separate entity and ignore hydrological interconnections and the socioeconomic relationships among the populations dependent on these tanks, this study is based on the premise that an understanding of the physical and socio-economic conditions of the tank cascade systems as a whole is a necessary condition for improving irrigation management.

The project has two components :

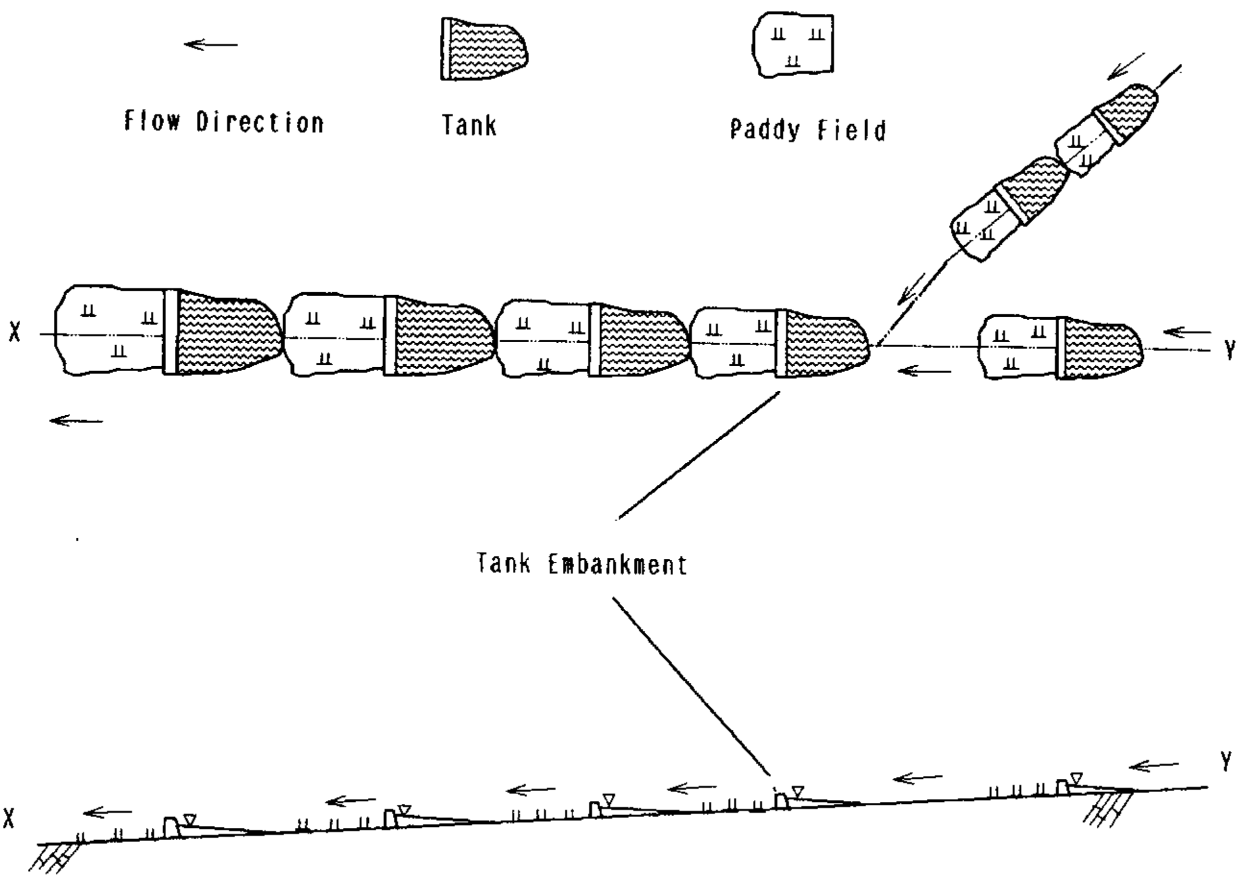
(1) A technical component which is firstly focussed on the solution of hydrological phenomena in an existing tank cascade irrigation system, then secondly, on demonstrating methods for developing the potentialities of a whole system with water balance simulation, considering the sustainability of irrigation; and

(2) A socioeconomic component which would inquire into local tank management functions, identifying the social and economic conditions, profitability of agriculture and resource allocation decisions which affect irrigation management within and between tanks. This component would also assess the institutional and environmental sustainability of the tank systems for irrigation management.

SCOPE OF THE REPORT

The present report has a limited purpose. It deals only with the technical component, and only with one season: *maha* 1991/92. (In Sri Lankan terminology this is the major of the two cropping seasons, whose duration at the study location is from October 1991 to March 1992.) This report presents data recorded at the site during that season, and offers a certain amount of initial analysis and discussion of these observations. It is intended that a report in similar format will be produced after each subsequent season. Undoubtedly, as data accumulates, deeper insights into the system's processes will be obtained, and the discussion and evaluation sections of these reports will grow stronger. At this stage, readers will understand that most of the deductions drawn from the data are of a preliminary kind.

Figure 1. Tank cascade irrigation system.



CHARACTERISTICS OF TANK CASCADES IN SRI LANKA

A tank cascade, or a chain of tanks, is a series of small reservoirs that are constructed at successive locations down one single common watercourse. Thus any excess water flowing from one tank in such a chain is captured in the next, downstream tank. Commonly, each tank in the cascade irrigates an area that lies downstream of it in the same valley; very often, this "irrigated command" may extend right to the edge of the water of the next tank, so that, when the tanks are full, there is a continuous alternation of water and irrigated cropland all along the valley bottom (see Figure 1). Terrain and climate usually dictate that the total area of water and of irrigated land are of a somewhat similar order, when the tanks are full.

Tank cascade systems are unique irrigation systems which originally flourished in the Dry Zone of Sri Lanka and in some parts of southern India. (In Sri Lanka, the Dry Zone is usually defined as those areas where the mean annual rainfall is less than 1,700 mm/year.) It is said that most of these systems had been constructed during ancient times in an attempt to maximize the total available water under limited water resources. For that purpose, every tank cascade system commonly held a series of small tanks, although they were different in scale or in complexity, respectively. Inside the system, the tanks are ranged one after another very closely along the small water courses. Surprisingly enough, today, we can see every cascade tank holding its own command area regardless of the scale of its catchment area.

It is often argued that such overcrowded conditions based on excessive reliance on tank water brought about overexploitation of the watershed and induced the collapse of sustainability of irrigation systems. However, with a strong demand for irrigable farmlands, tank cascade systems were distributed at high density around the Dry Zone with the aim of overcoming the deficiency of irrigation water due to such disadvantages as seasonally ill-balanced rainfall, limited catchment area, lack of provision for water transfer, and so on.

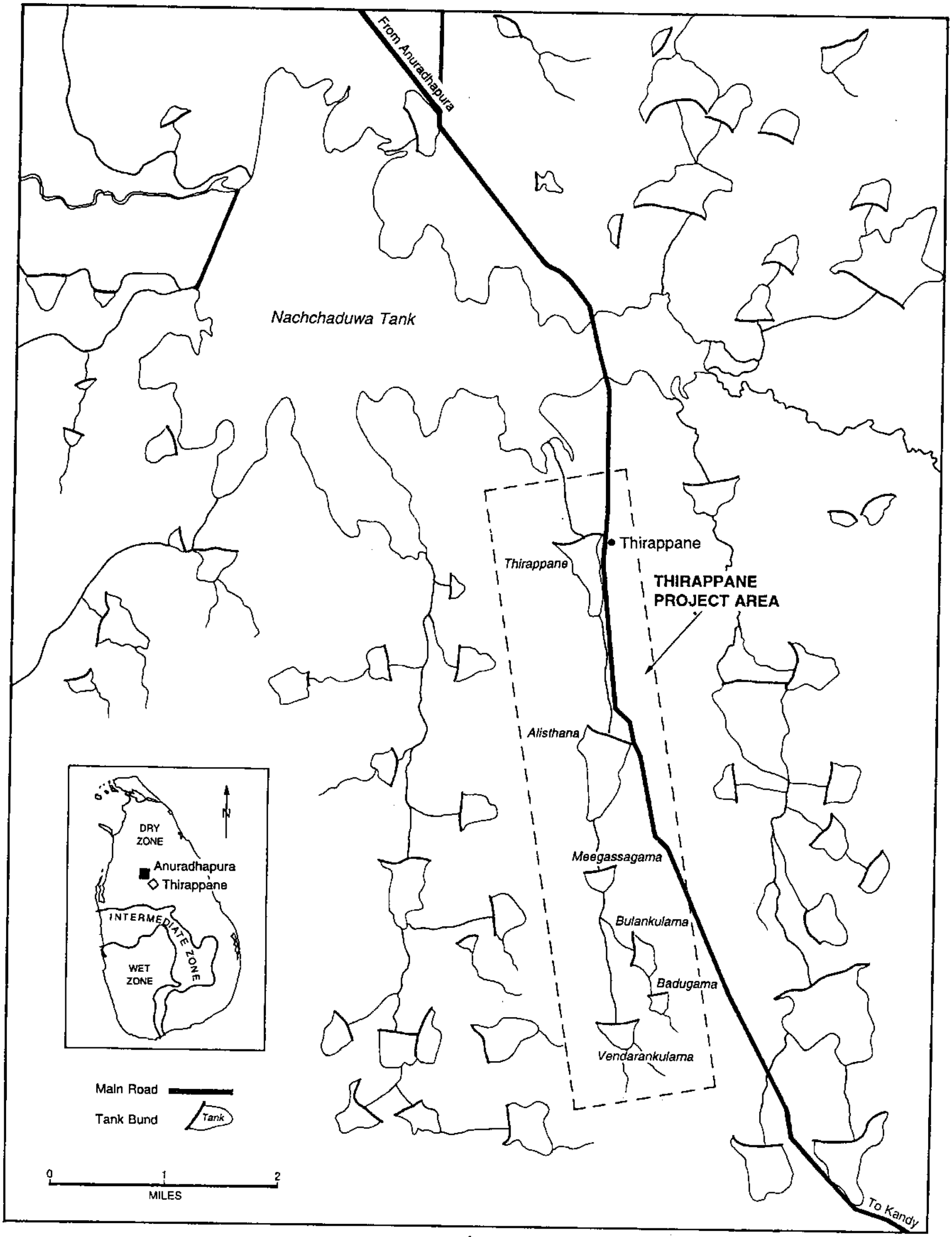
In the light of the following functions, the interconnected tank irrigation system has a high potentiality as a water use system :

(1) Function of re-storing and re-using drainage return-flow which is recycled within the system;

(2) Buffer function of alleviating the imbalance between water demand in the command area and water supply from the tank, which occurs owing to the fluctuation of both field water requirement and rainfall-runoff discharge.

With intensification of these functions over the system, the total amount of wasteful water issue could be minimized, and consequently, the total available water within the system could increase. Of course, careful managerial cooperation among tank blocks is necessary to produce these practical results. However today, in reality, each tank block is solely operated by its own village. Besides, no operational knowhow to manage a total cascade system over an irrigation period has yet been established. The users can judge neither the best construction of a whole system nor the optimal size of a command area. Thus, nowadays, they may not always be making full use of the potentialities of their system.

Figure 2. Nachchaduwa Dam and neighbouring tank cascade systems.



DESCRIPTION OF THE STUDY SITE AT THIRAPPANE

Location

Field work is being carried out in the Thirappane area which is about 30 km south from the ancient capital city of Anuradhapura in the North-Central Province of Sri Lanka. This area contains six connected tanks and their respective command areas ranging along a small water course which finally connects to Nachchaduwa Dam. The complete system of 6 tanks and their command areas is about 8 km in overall length, and 2 km wide. In this region, a number of tank cascades flow directly toward this huge, ancient dam (Figure 2). This area is noted for its network of tanks, representative of the Dry Zone of Sri Lanka. Government-managed tank rehabilitation projects are also underway in this area.

The Six Tanks

Strictly, the six tanks being studied in the project do not form a single cascade, but are a cascade of four tanks with a tributary branch of another two.

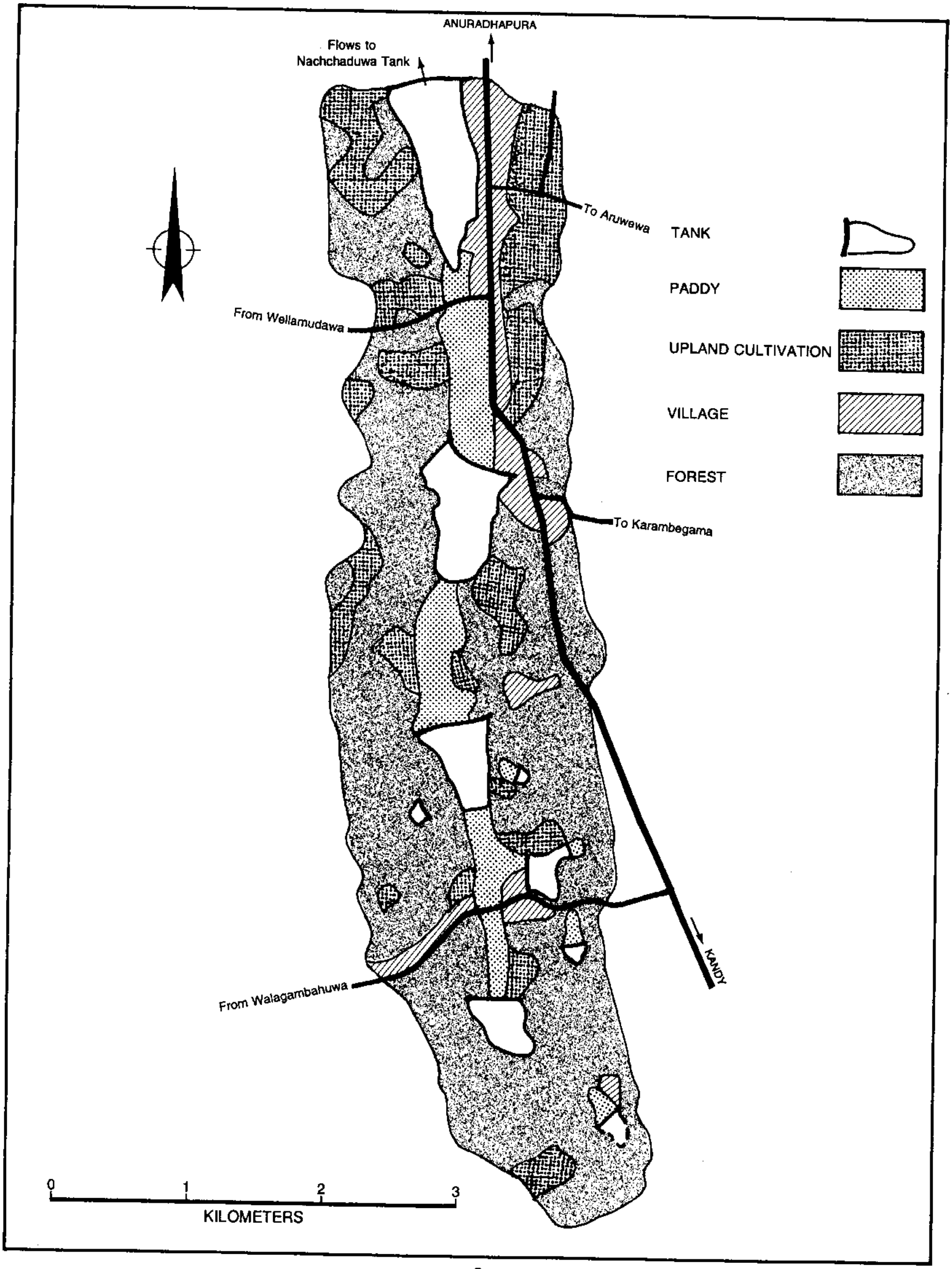
The main cascade, as shown in Figure 2, consists of the tanks of Vendarankulama, Meegassagama, Alisthana, and Thirappane (in downstream order). Badugama and Bulankulama, which are very much smaller than any of these main four, lie on the tributary branch, which flows in from the right between Vendarankulama and Meegassagama.

Figure 3 shows the overall distribution of the main land-use categories in the whole catchment area where the six tanks are situated. In this the relationship of the tanks, irrigated command areas, villages, associated rain-fed cultivated lands, and forests, can be clearly seen.

Upstream of the top tanks, Vendarankulama and Badugama, the catchment is forested and the watershed boundary is reached in about half a kilometer. At the downstream end, Thirappane Command reaches to the edges of the Nachchaduwa Reservoir.

The command areas of Vendarankulama and Bulankulama merge together, creating opportunities for water transfer between them. Drainage water from the Vendarankulama Command can be used by the Bulankulama farmers.

Figure 3. Land use in catchment of Thirappane Tank Cascade.



Command Areas

Command area surveys were carried out in all tank blocks in 1992. Principal features are shown in Figures 4 to 9. The irrigable command area fluctuates every season mainly due to the meteorological situation. Nowadays, owing to the intense pressure on farmland, the tail end of the command area has come extremely close to the surface zone of the water of the next downstream tank, and the boundary between them is not always clear (see Figure 3). The size of the field lots depends on the gradient of the field and so on, but is very small in general (less than 0.05 ha).

Table 1. Irrigated areas.

Name of tank	Nominal command area (1) ha	Irrigated area 1991/1992 maha (2) ha	(2)/(1) %	Number of families irrigating	Average size of family irrigated area ha
1. Vendarankulama*	18.2	18.2	100.0	17	1.07
2. Meegassagama	32.5	32.5	100.0	34	0.96
3. Alisthana	39.1	32.4	83.1	35	0.93
4. Thirappane	34.5	26.2	75.9	56	0.47
5. Badugama	2.4	1.1	45.8	2	0.55
6. Bulankulama	17.1	17.1	100.0	41	0.42

* Part of the command area of Bulankulama has been irrigating with drainage water from Vendarankulama (Figure 9).

Catchment Areas

The catchment area of every tank and every command area were surveyed with aerial photographs (taken in 1982). In general, a considerable part of the catchment is covered with forest, but it is often said that the proportion of forest has been gradually diminishing under the pressure of extensive shifting (slash-and-burn) cultivation and deforestation. It is presumed that they have been exerting bad influences on the runoff discharge pattern in the watershed and on the water use in irrigation systems, too. Hence, to arrest these trends, afforestation projects are in progress in this area since recently.

Table 2. Catchment areas of respective tanks.

Name of block	Catchment area (km^2)
1. Vendarankulama	1.95
2. Meegassagama	3.56
3. Alisthana	3.70
4. Thirappane	4.48
5. Badugama	0.26
6. Bulankulama	0.64

It should be noted that each area given in Table 2 represents the independent *increment* of catchment area, supplying water directly to that particular tank.

Figure 4. Command area of Vendarankulama Tank.

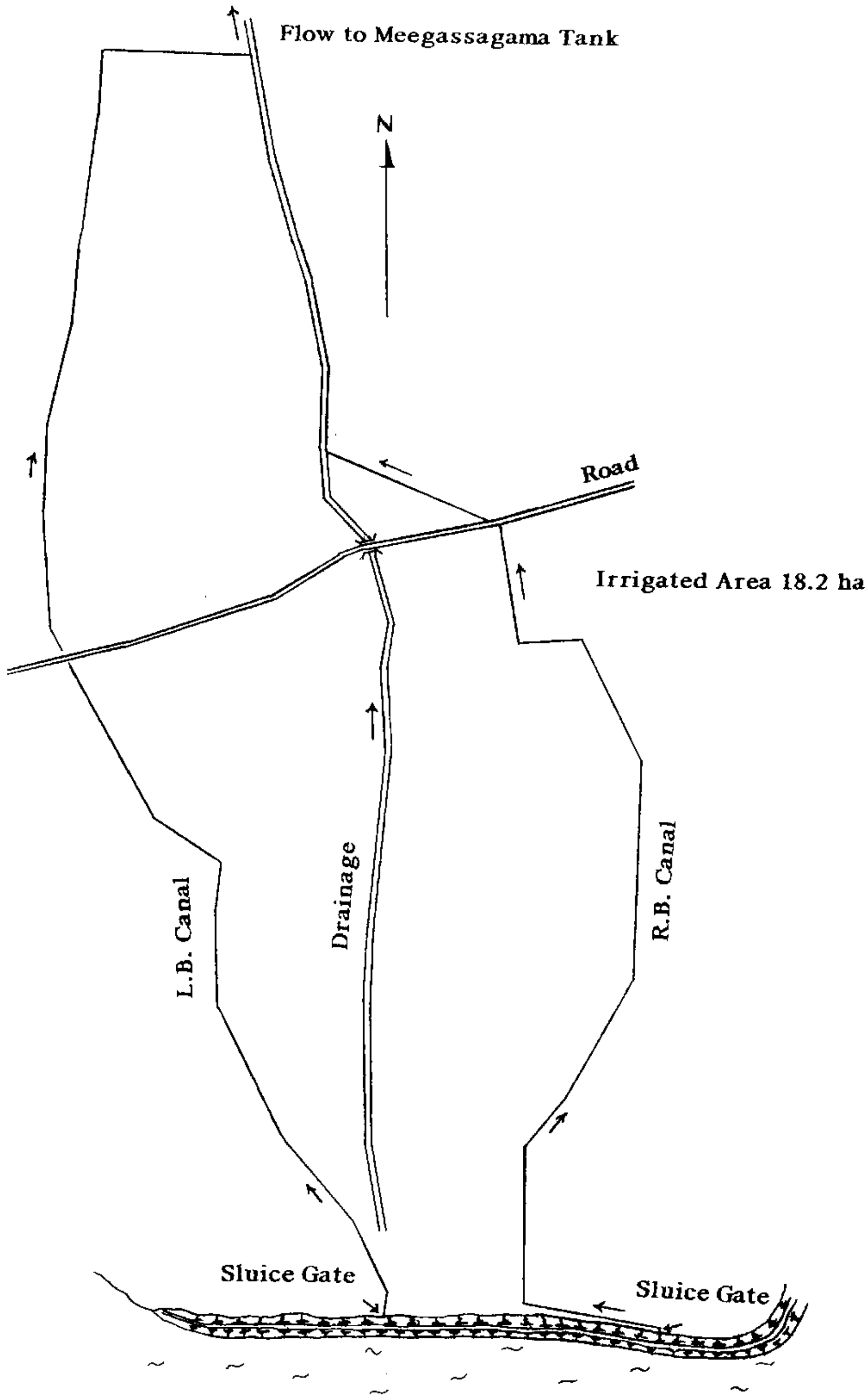
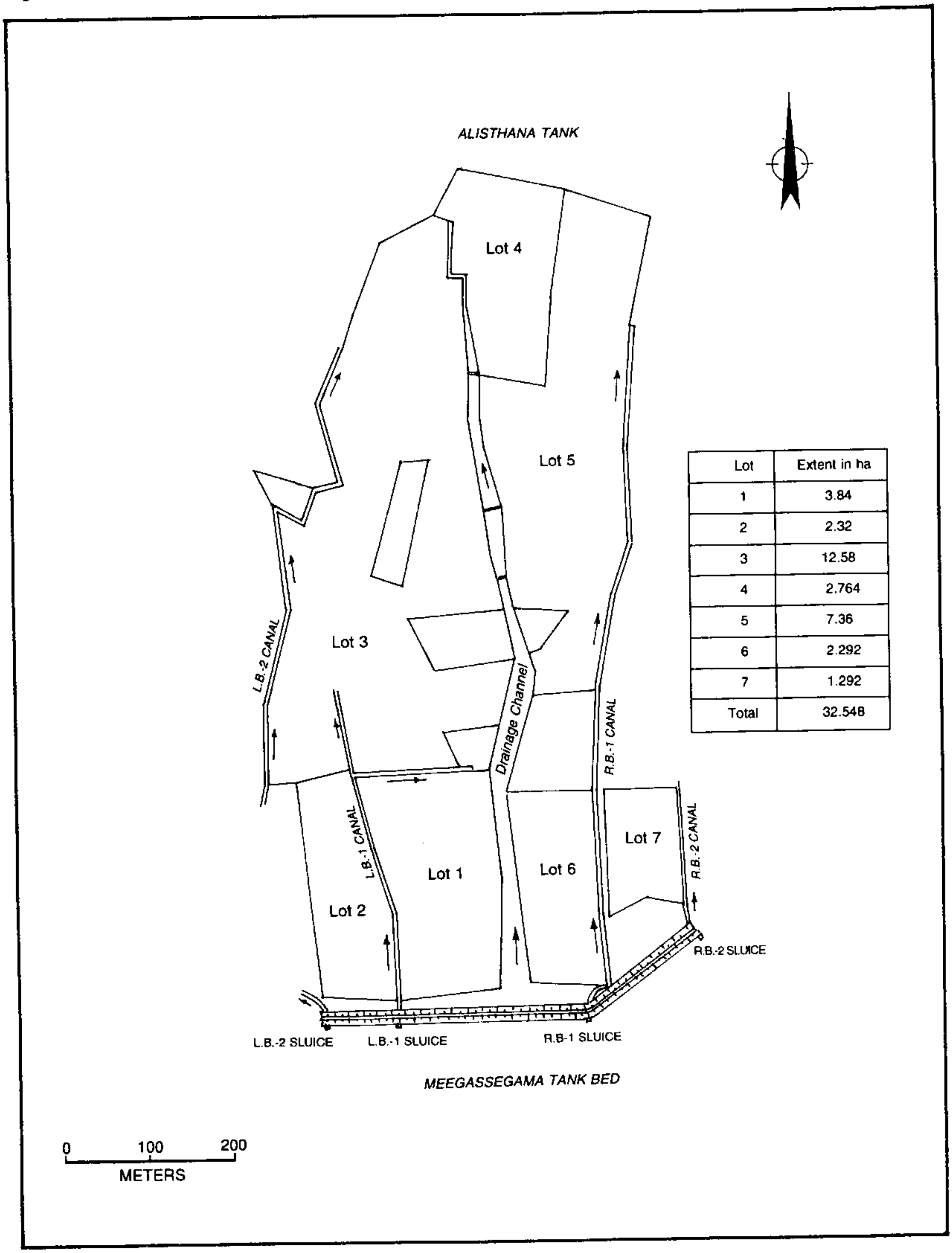
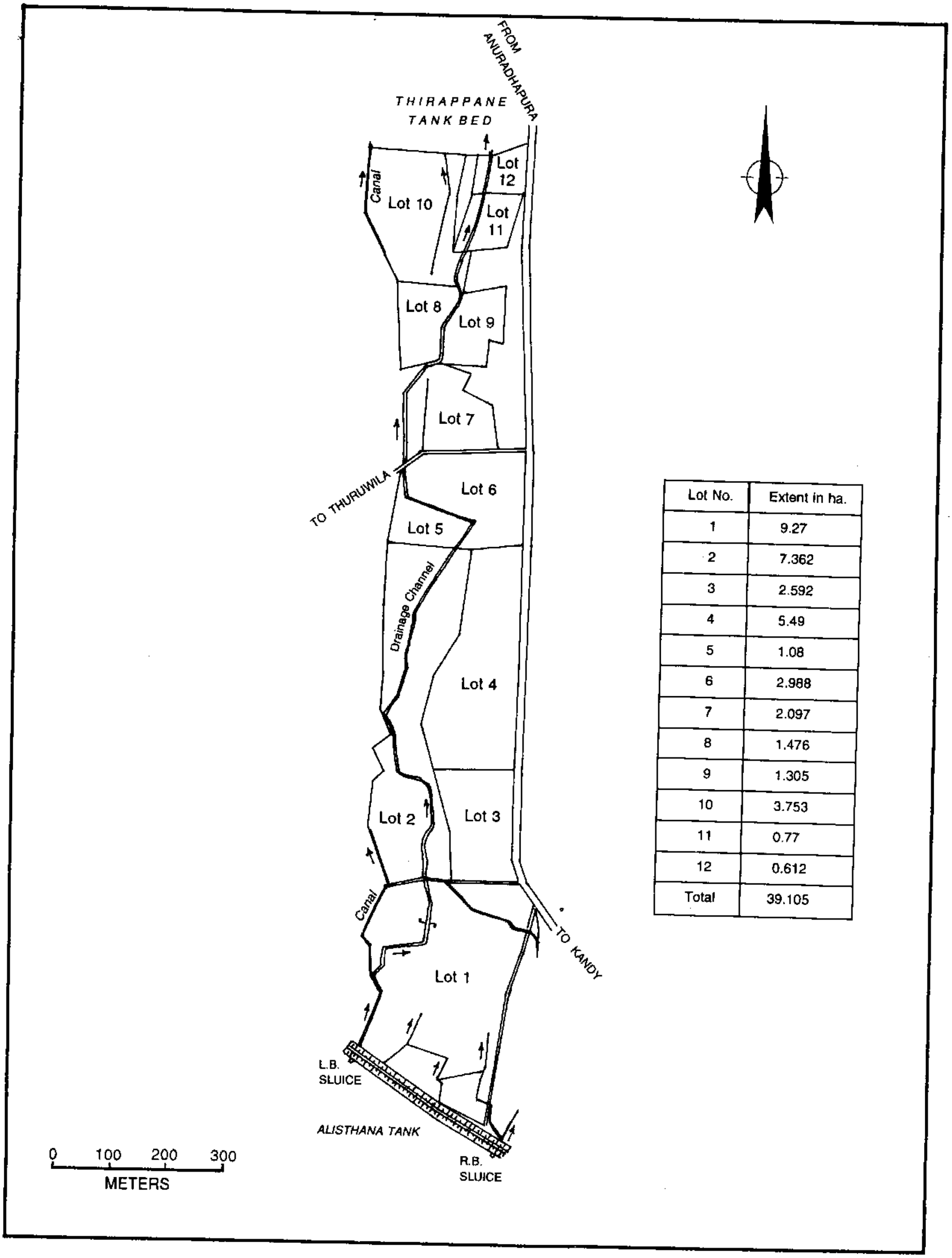


Figure 5. Command area of Meegassagama Tank.



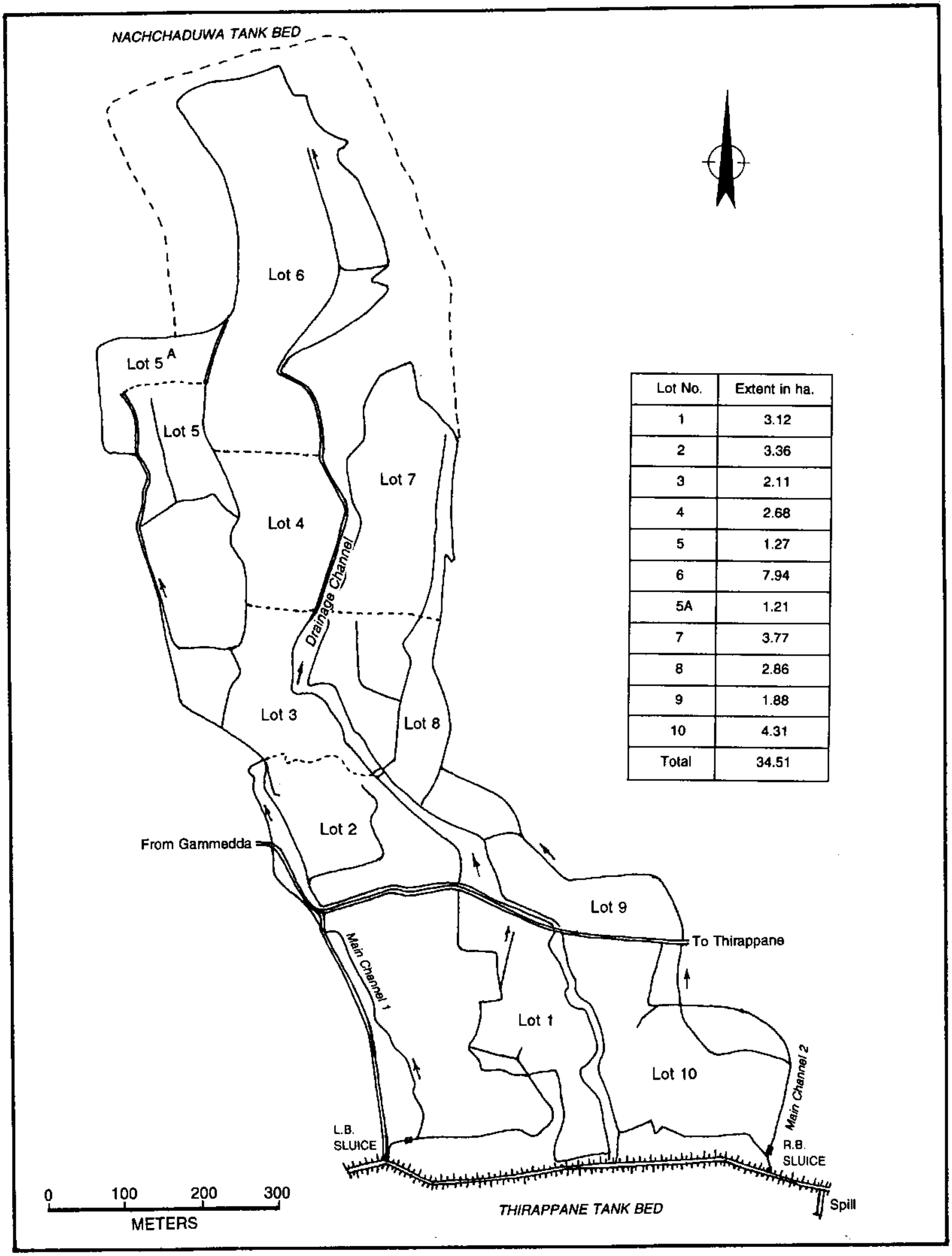
Lot	Extent in ha
1	3.84
2	2.32
3	12.58
4	2.764
5	7.36
6	2.292
7	1.292
Total	32.548

Figure 6. Command area of Alisthana Tank.



Lot No.	Extent in ha.
1	9.27
2	7.362
3	2.592
4	5.49
5	1.08
6	2.988
7	2.097
8	1.476
9	1.305
10	3.753
11	0.77
12	0.612
Total	39.105

Figure 7. Command area of Thirappane Tank.



Lot No.	Extent in ha.
1	3.12
2	3.36
3	2.11
4	2.68
5	1.27
6	7.94
5A	1.21
7	3.77
8	2.86
9	1.88
10	4.31
Total	34.51

Figure 8. Command area of Badugama Tank.

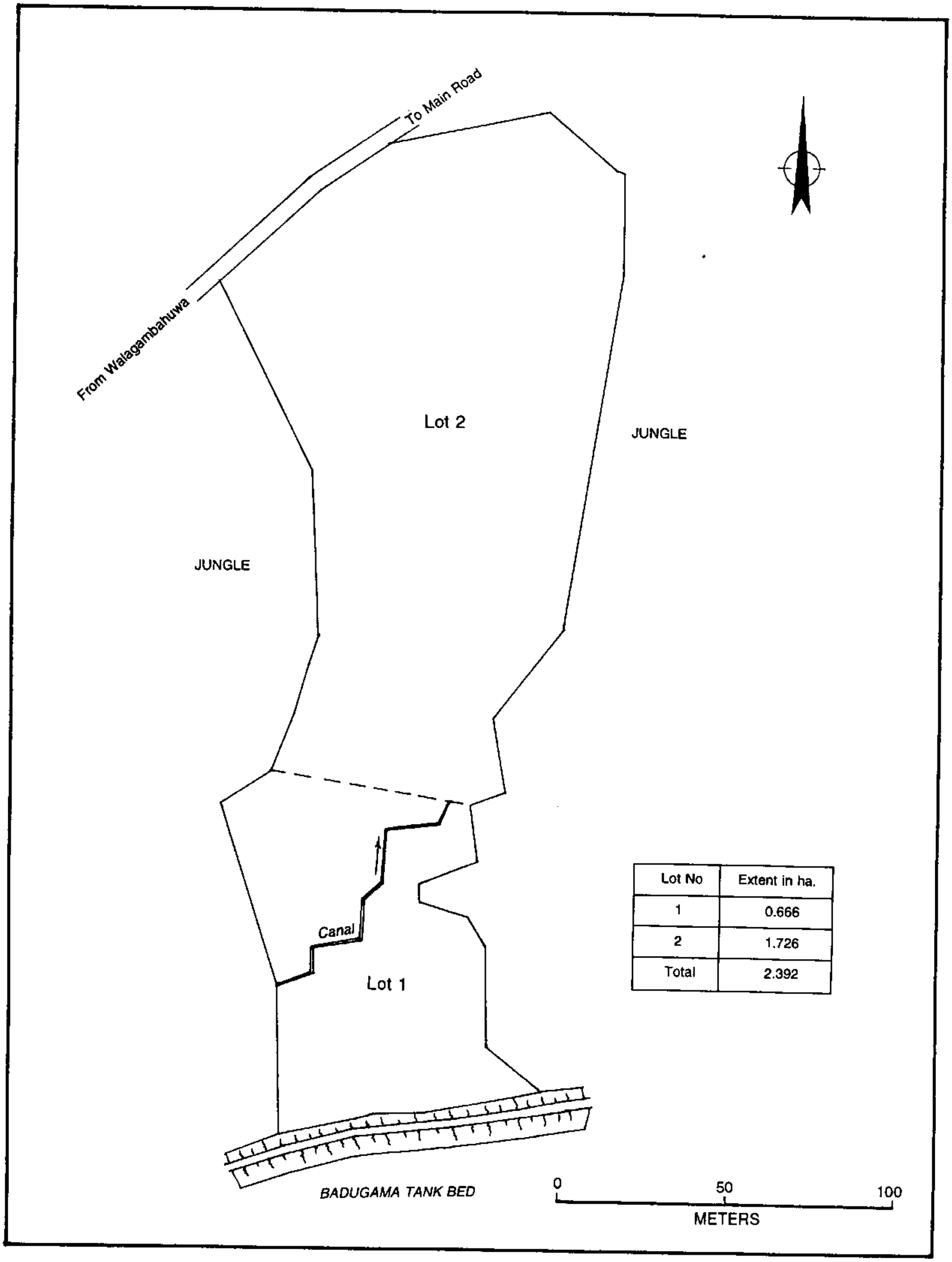
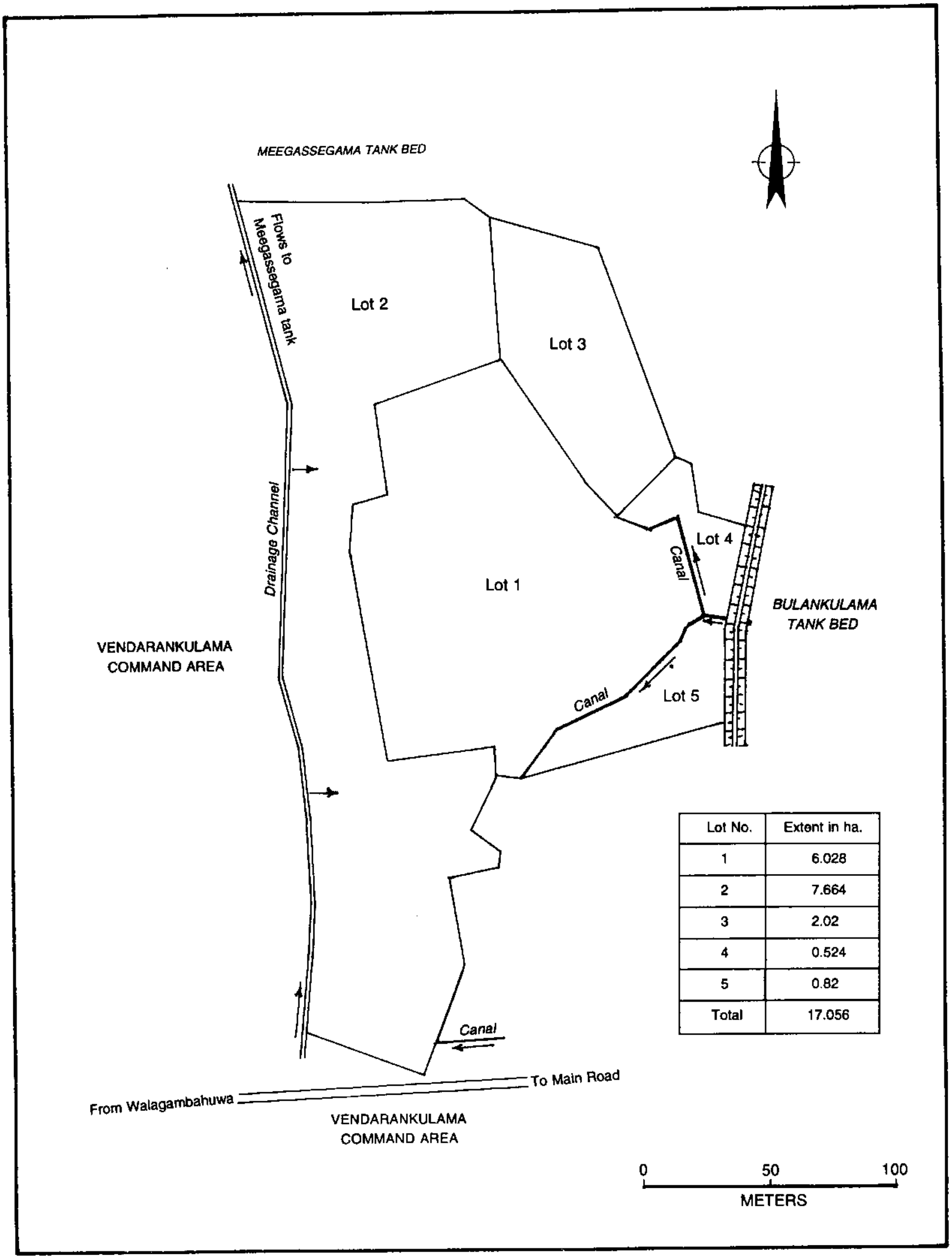


Figure 9. Command area of Bulankulama Tank.



Lot No.	Extent in ha.
1	6.028
2	7.664
3	2.02
4	0.524
5	0.82
Total	17.056

Tank Capacities

In 1992, tank-bed surveys were carried out for all tanks and height-volume diagrams were prepared. It can be seen from the following table that the tank sizes increase steadily as one proceeds down the cascade.

Table 3. Dimensions of tanks.

Name of tank	Height (m)	Water spread area (km^2)	Effective capacity (1,000 m^3)
1. Vendarankulama	2.9	0.13	220
2. Meegassagama	3.0	0.30	360
3. Alisthana	2.8	0.51	580
4. Thirappane	3.2	0.60	790
5. Badugama	2.2	0.07	80
6. Bulankulama	2.1	0.10	100

Agricultural Jurisdiction

With regard to irrigation construction and management, this area is within the jurisdiction of the Department of Agrarian Services (DAS) which is responsible for the minor irrigation work on systems with command areas less than 80 ha. Essentially, the systems at Thirappane Cascade are farmer-owned and farmer-managed, but in their relationship with the government the channel is the DAS. Formerly this was a central government department, but in recent years its functions were transferred to the Provincial Government. More recently again, they have been delegated farther, to the Divisional Secretariat, which is at Thirappane.

Land Use

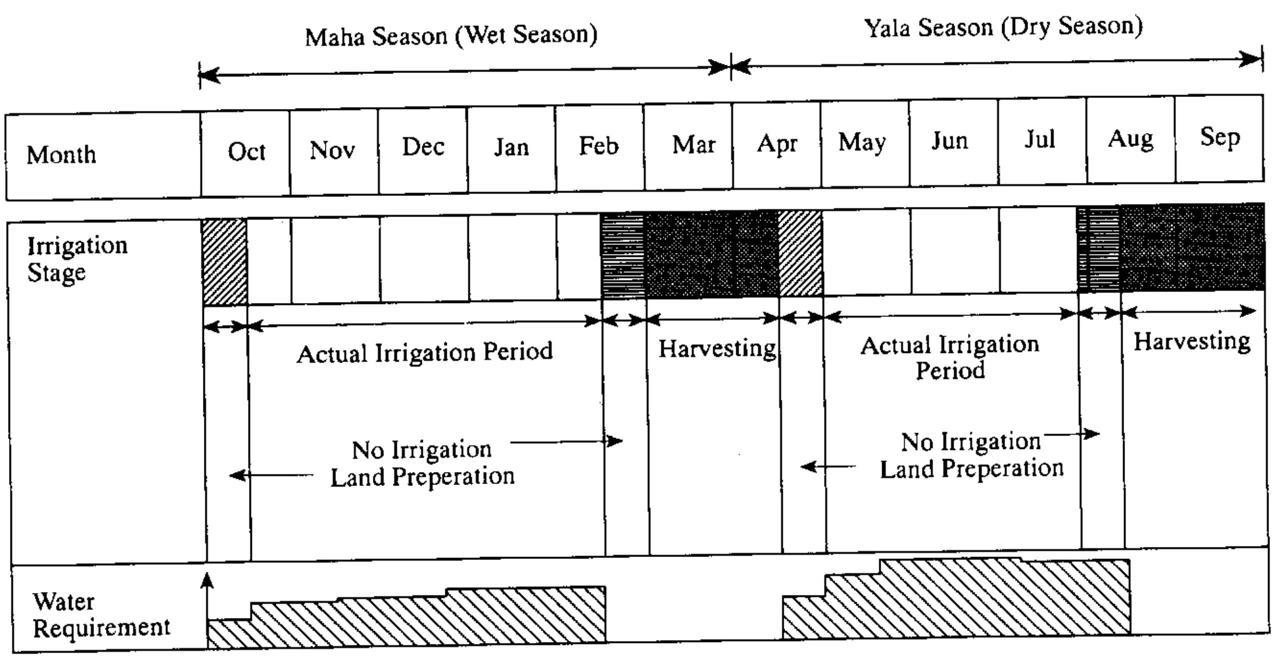
During the maha or wet season, which normally commences in October or November, irrigated rice fields are predominant in this area. Only in the case of upland land use are other field crops, for example, chili, soybean, etc., cultivated. On the other hand, in the *yala* or dry season, the irrigated rice field area reduces sharply due to serious water shortage. Consequently, the ratio of other crops to rice increases relatively during yala. On the whole, the proportion of cash crops has been rising up year by year with the increase of privately owned wells. The total irrigated areas of the respective tanks are planned at the beginning of each new season through farmers' meetings with the presence of officers of the Department of Agrarian Services. Each tank community conducts its own such meeting separately.

Cropping Pattern

The standard annual rice cultivation pattern in this region is illustrated in Figure 10. However, the actual patterns do not always follow this standard due to various factors; for example, meteorological instability, lack of manpower and equipment, failure in the farmers' mutual agreement on the cropping schedule or water allocation, and so on.

Rice double cropping is targeted every year in spite of the chronic water shortage during the dry season. Annual cultivation is classified into two types, namely, maha and yala. During the maha cultivation, the farmers can expect relatively more rainfall compared with yala. Hence, maha is the main cultivation season here and the farmers can keep comparatively wide, irrigated farmlands. In this season, they usually adopt long-term varieties of rice, considering the relatively abundant rainfall. On the other hand, in yala, they are compelled to adopt short-duration varieties.

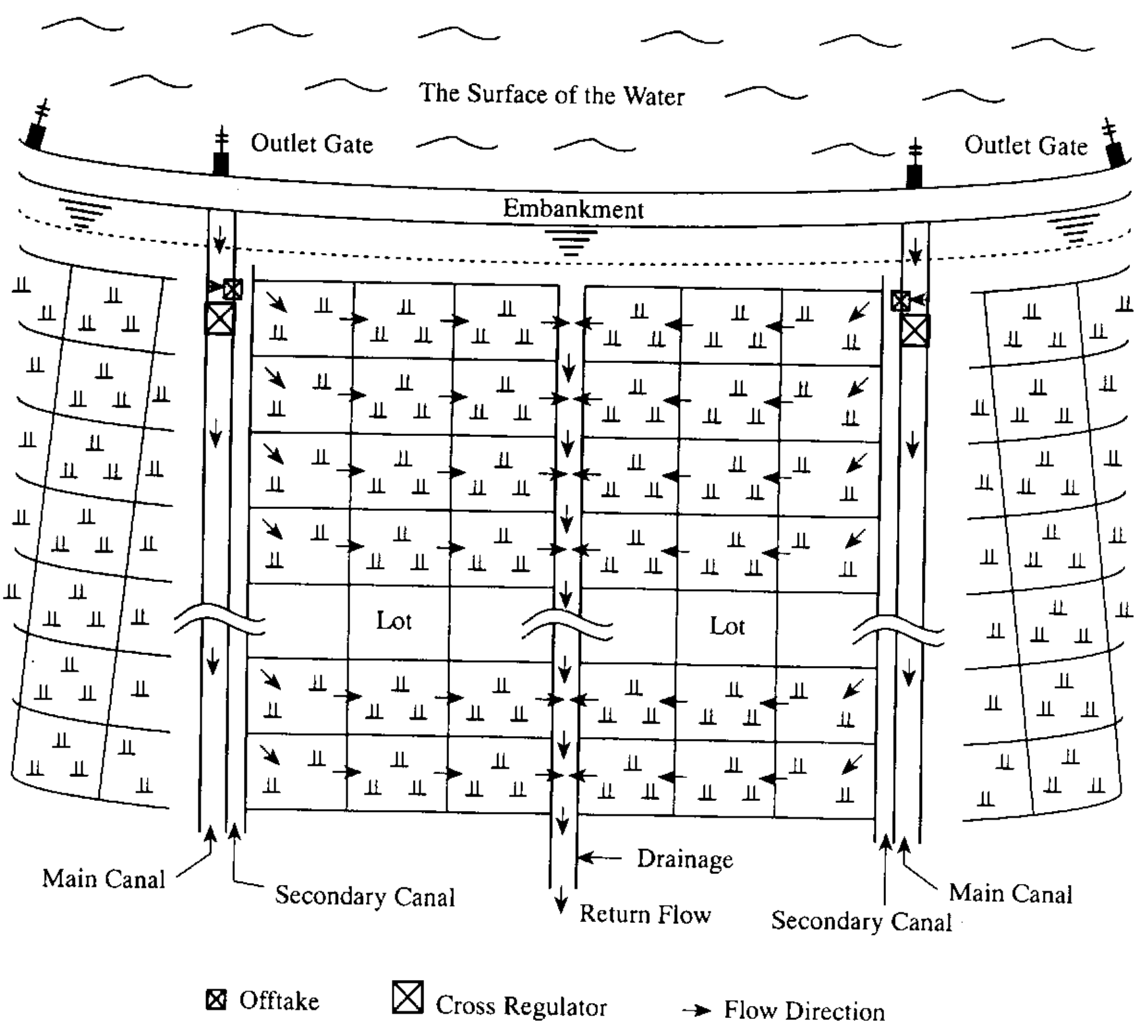
Figure 10. Rice cultivation calendar in Anuradhapura District.



Water Delivery System

Figure 11 shows a simplified illustration of the irrigation network of the Thirappane area. In reality, however, each tank block still does not have a well-ordered canal network except at Meegassagama, because standard land improvement work has not been practised here. Every tank has some outlet work and they are divided into two types. One is the vertical tower type and the other is the sluice gate type. In the tower outlet, used in the smallest tanks, water flows out down a hollow tower built of cylindrical rings: as the tank water level rises or falls, the operator can add or remove rings to keep the tower top close to the water level, but no other control is available. On larger tanks, more conventional,

Figure 11. Water delivery system.



variable sluice gates are usual. Outlet works are immediately connected to main canals. The sizes of command areas controlled by outlet works vary. The command area of each outlet is commonly divided into several rotational blocks which are managed in a traditional order. However, water rotations are often disrupted because of poor hardware and poor management practices.

In some cases, main canals are provided with some cross-regulators. They have offtakes in places just upstream of those cross-regulators. Secondary canals which are installed only in the Meegassagama block run parallel to the main canals. Each offtake covers around 1 or 2 ha of command area. Earthen inlets are provided at the levees of the field plots which are confronting the main or secondary canals. As shown in Figure 11, as is usually the case of plot-to-plot irrigation, water from the inlet is led to the next plot one after another gravitationally, through temporary ditches in each plot. Finally, after passing through some field plots, excessive intake water, if any, is led to the outlet of the tail-end plot which is facing the drainage canal. However the location and arrangement of drainage are also sometimes unclear. Occasionally, water does not reach the terminal lots. Hence, drainage water is reused there. For this purpose, farmers often construct small embankments across the drainage canal to dam it up.

Rice Seeding

In this region, direct seeding in the saturated soil condition is predominant with regard to rice seeding. The farmers usually begin to plant in turn soon after the completion of land preparation. On the other hand, the Department of Agrarian Services has been recommending transplanting with an aim at intensive cultivation.

Land Preparation

Land preparation work is carried out with tractors to speed up the work. Both walking-type and riding-type tractors are operated for twice plowing and puddling. Although the period for land preparation varies depending on the rainfall condition at the stage, on the scale of command area, and further, on the number of tractors available, it usually takes over 30 days to complete this work in the maha season despite the official standard of 15 days. Puddling water mainly relies on the rainfall in the initial stage of the maha season, while in the yala season it relies on both rainfall and tank storage water because of the lack of precipitation. Especially in the maha season, farmers are anxious to finish this work as early as possible because they have to complete harvesting before the following April, when there will be a considerable amount of convectional rainfall under the influence of monsoon circulation which disturbs harvesting.

Irrigation Technique

Regarding irrigation technique, plot-to-plot irrigation as well as rotational irrigation is basically adopted for the purpose of realizing water saving. Fortunately, the representative lowland soil predominant for rice cultivation in this area is Low-Humic Gley Soil which is outstanding for its low permeability. The standard irrigation interval around this area is 7 days and the standard instalment of water supply from the inlet is about 75 mm, which is determined by experience in practical water management, and is higher than the official standard value (about 60 mm/7 days) in this region.

METHODOLOGY OF THE STUDIES

Technical Component

The technical component of this study will proceed according to the steps indicated in Table 4.

Table 4. Process of the area-wide water balance study.

Stage	System level	Field level
1. Data collection and data analyses	(1) hydro-meteorological data (2) operational data (3) catchment area (4) tank height-volume curve	(1) field water requirement (2) command area
2. Water balance computation in actual state	inflow --> stock --> issue --> water consumption --> return-flow [circulation]	(1) net water requirement (2) gross water requirement (3) design water issue
3. Estimation of coefficients	(1) runoff percentage (2) tank water loss ratio (3) return-flow ratio	(1) effective rainfall ratio (2) ratio of the management water requirement
4. Completion of the model	Combining of each tank block's model	
5. Simulation	Simulation for the whole system	

Structure of the Water Balance Model

The basic water balance structure of an area such as Thirappane can be simply illustrated as in Figure 12. Here, respective tank blocks are interconnected hydrologically. Basic equations which express the hydrological phenomena over a whole system are as follows.

1. Inflow into the tank by runoff discharge[1]

$$QA_{i,t} = Wx_i * fx_i * R_{i,t} \quad \text{--------------------} \quad (1)$$

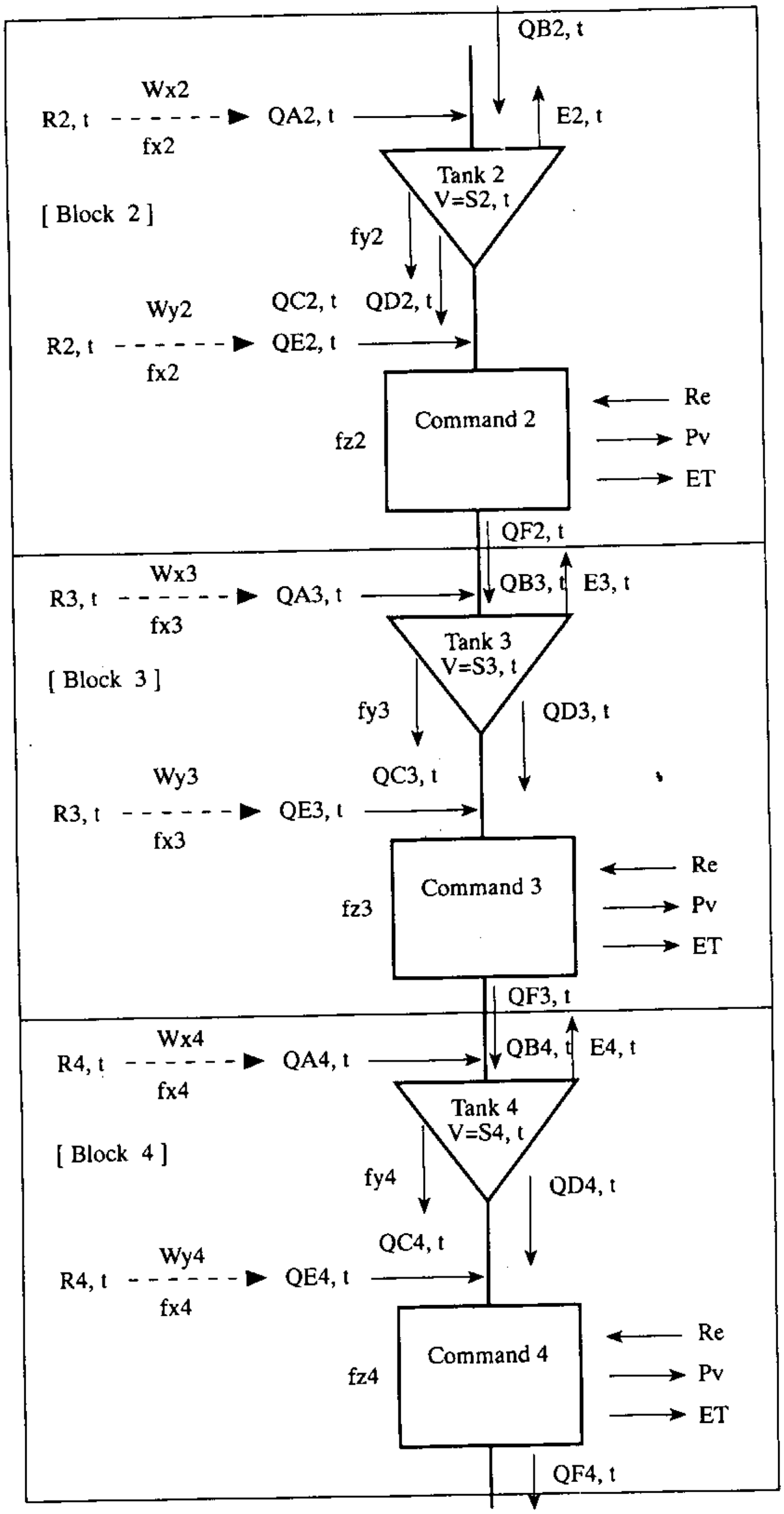
2. Inflow into the command area by runoff discharge[2]y

$$QE_{i,t} = Wy_i * fx_i * R_{i,t} \quad \text{--------------------} \quad (2)$$

[1]Runoff percentage will change according to the rainfall pattern, soil condition and so on. Therefore the rainfall-runoff analysis will be carried out based on the long-term data.

[2]Water seepage-loss ratio will be a function of the tank water level.

Figure 12. Structure of water balance model.



3. Structure of outflow from the tank[3]

$QC_{i,t} = QD_{i,t} + E_{i,t} + (fy_i * S_{i,t-1})$ --------- (3)

4. Water balance structure on tank water storage[4]

$QA_{i,t} + QB_{i,t} = QC_{i,t} + S_{i,t}$ ---------------- (4)

5. Structure of return-flow from the command area[5]

$QF_{i,t} = (QC_{i,t} - E_{i,t} + Re_{i,t}) * fz_i$ ------- (5)

6. Return-flow turning into inflow[6]

$QB_{i,t} = QF_{i-1,t} + QE_{i-1,t}$ -------------- (6)

7. Periodical change of tank storage volume

$S_{i,t} = S_{i,t-1} + ds_{i,t}$ ------------------------ (7)

$QA_{i,t}$: Runoff discharge from the catchment of the tank.
$QB_{i,t}$: Return-flow which inflows from the upper-stream block.
$QC_{i,t}$: Total outflow from the tank including evaporation, leak loss, and water issue.
$QD_{i,t}$: Water issue from the tank.
$QE_{i,t}$: Runoff discharge from the catchment of the command area (excluding the effective rainfall in the command area).
$QF_{i,t}$: Return-flow which flows down into the downstream tank.
$R_{i,t}$: Precipitation.
$S_{i,t}$: Actual storage volume in the tank at the end of the t^{th} period.
$ds_{i,t}$: The change of storage volume during the t^{th} period.
$E_{i,t}$: Evaporation from the surface of tank.
$Re_{i,t}$: Effective rainfall consumed in the command area.

---

[3]Return-flow ratio will also change according to various conditions of the fields. Usually however, the mechanism of the return-flow ratio is quite intricate. Inquiry into the mechanism of the return-flow is not the goal of this study. The purpose of this model is to simulate approximately the mechanism of the water balance of the interconnected tank irrigation system in order to study long-term water management. Therefore, in this report, this ratio will be expressed simply as long as the determined ratios satisfy this purpose.

[4]$QA_{i,t} = V[H(t2)] - V[H(t1)] + QC_{i,t}$

V[H(t1)] : tank water storage(V) equivalent to the tank water level(H) at the start of the stage(t).

V[H(t2)] : tank water storage(V) equivalent to the tank water level(H) at the end of the stage(t).

[5]Equation (5) considers the influence of the tank seepage loss on the return-flow.

[6]Equation (6) indicates the hydrological interconnection between two tanks.

Wx_i : Net catchment area of the tank.
Wy_i : Net catchment area of the command area.
fx_i : Runoff percentage.
fy_i : Water seepage-loss ratio from the tank.
fz_i : Return-flow ratio.

i : Number of tank block (1,2,3,4,5,6).
t : Number of irrigation stage (1,2,........,n). Each stage consists of 5 days.

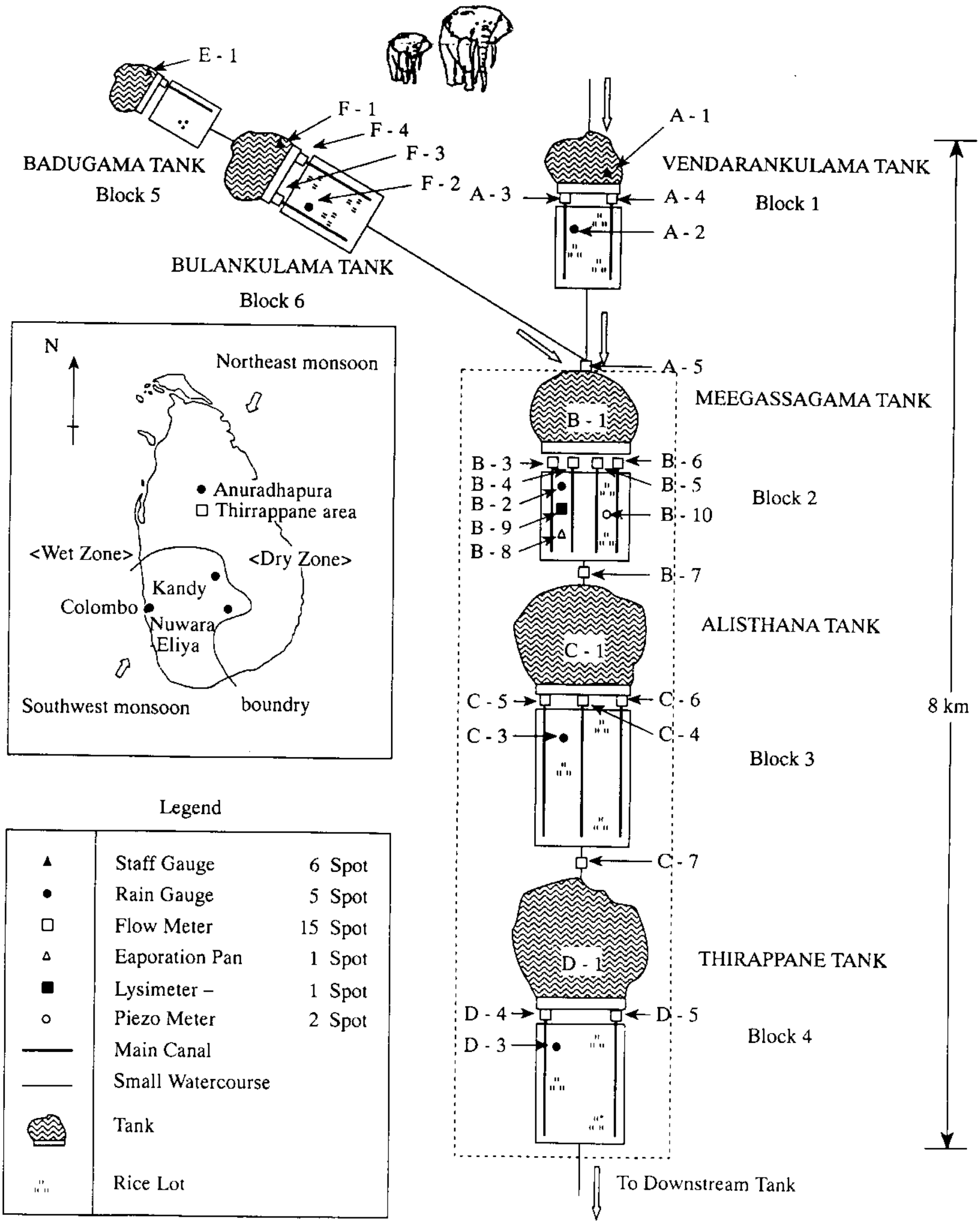
According to these seven formulas, the water balance computation in an actual state will be carried out in turn, in the downstream direction according to the water balance sheet. Throughout one irrigation season, this computation will be practised every cluster of 5 days in turn. As a result, the unknown coefficients of the model, such as runoff percentage, water loss ratio from the tank and return-flow ratio will be estimated on the basis of several seasons' computation, and at the same time, the simulation model of water balance in the actual state will be completed.

After that, for the purpose of examining how to intensify the system performance of a whole system, water balance simulation will be tried in various cases by way of varying the value of factors which have a great influence on the hydrological phenomena. Both structural and operational factors will be the targets of the alteration.

Socioeconomic Component

The socioeconomic component of these studies is not being reported in detail in the present seasonal report. Field data collection began later, for this component, than for the technical component. A general review of the socioeconomic situation, and of the field data collecting program, is expected to appear in the Maha 1992/1993 Seasonal Report in this series.

Figure 13. Data collecting system.



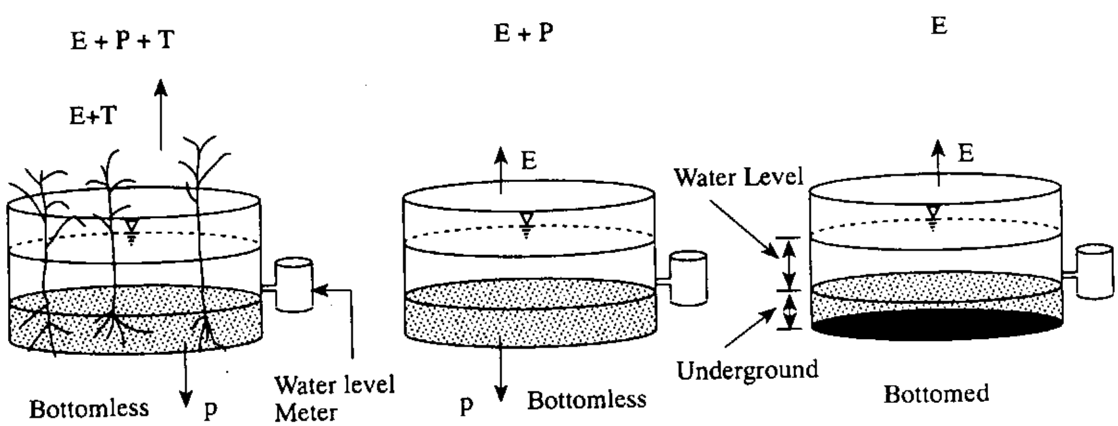
DATA COLLECTING SYSTEM

A major part of the data collecting system was established before the 1991/1992 maha season. Equipment locations are shown in Figure 13. The basic units on each of the main tanks were a staff gauge in the tank itself; parshall flumes for flow measurement on each of the canal outlets (two to four in number), from the tank to the command area; another parshall flume to measure the collected return drainage flow before it enters the next downstream tank; and a rain gauge in the command area.

The Meegassagama Command, at the middle of the cascade, was more intensively equipped, with an evaporation pan, piezometers, and a set of three lysimeters under different conditions. Figure 14 shows how these can be used to distinguish between evaporation, evapotranspiration, and percolation rates.

Readings on all these instruments are taken daily. The Meegassagama instruments, because of their central position, are considered to be applicable to the entire cascade.

Figure 14. Measurement of water requirements by lysimeter.



DATA COLLECTED IN THE 1991/1992 MAHA SEASON

Rainfall

Figures 15 to 19 illustrate the daily point-rainfalls measured by rain gauges distributed in each tank block. Total precipitation during the period from 20 October to 31 March was approximately 800 mm (Table 5). Most of the rainfall was concentrated in November and December. Especially on 29 December, extremely heavy rainfall (over 100 mm) was observed in each block, and at the same time, spill water was observed at all the tanks. Fluctuation curves of the tank water level also proved the occurrence of spill water (Figures 31-36 on pp. 34-36). Rainfall data of this season certify the irregular rainfall pattern in this region, which has been often pointed out. In the meantime, if a considerable amount of spill water is observed annually, the enlargement of tank capacities deserves consideration in the future.

Table 5. Precipitation in the 1991/1992 maha season (mm) (from October 20 to March 31).

Name of the block	October	November	December	January	February	March	Total
Vendarankulama	152	125	345	20	0	0	641
Meegassagama	152*	267	366	18	0	0	802
Alisthana	152	256	381	30	0	0	819
Thirappane	152	281	396	29	0	0	857
Badugama, Bulankulama	152	290	425	20	0	0	886
Average	152	244	383	23	0	0	801

* In October, data were collected only in Meegassagama, because the installations were not in time with regard to the other blocks. Therefore, the other blocks tentatively adopted data collected from Meegassagama.

Figure 15. Daily precipation at Vendarankurama, October 1991-March 1992.

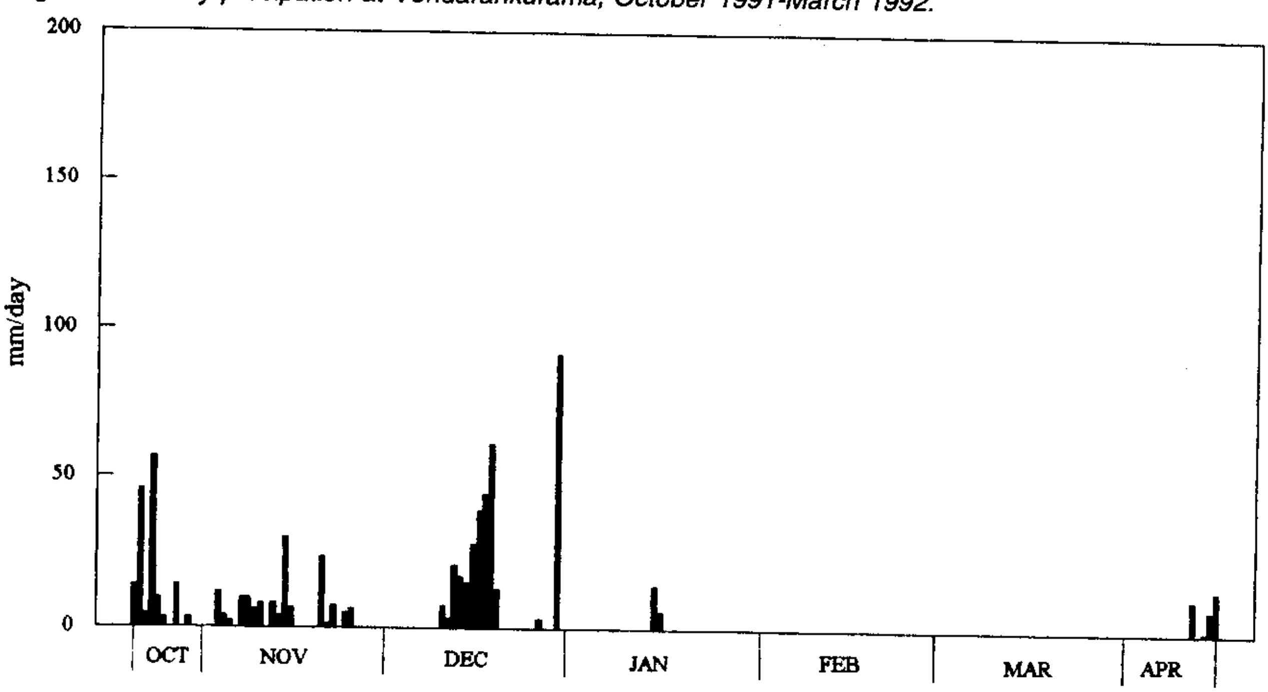


Figure 16. Daily precipation at Meegassagama, October 1991-March 1992.

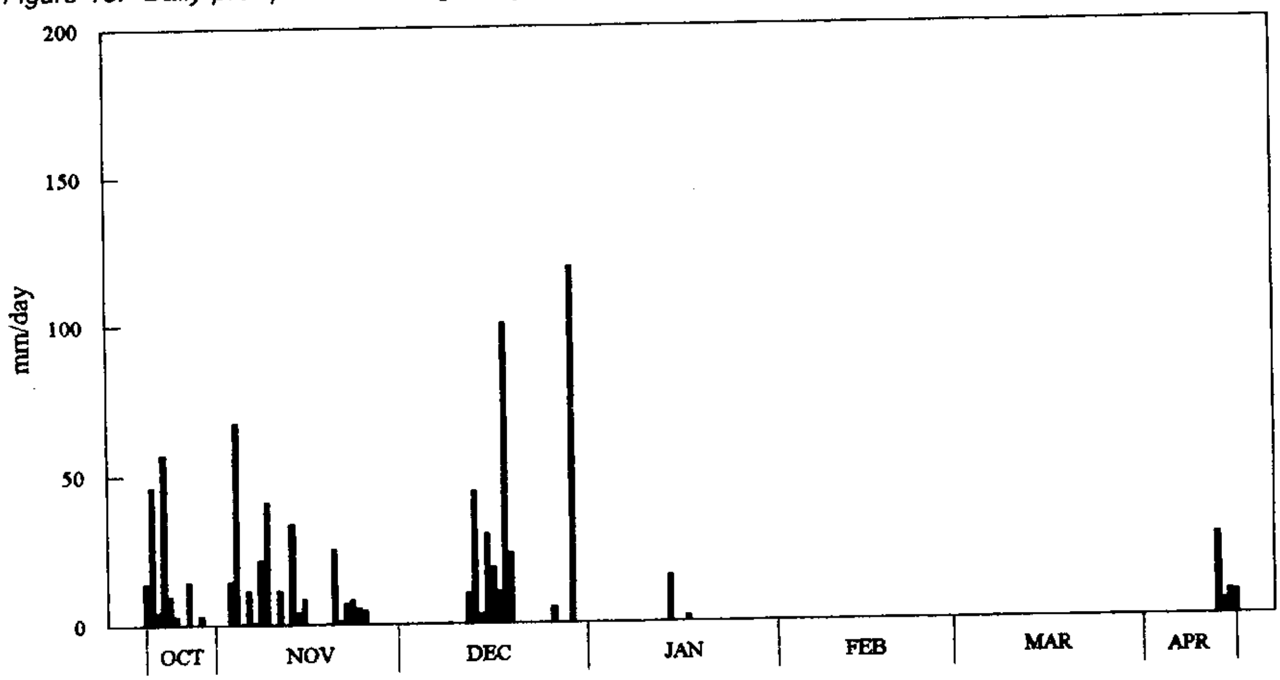


Figure 17. Daily precipation at Alisthana, October 1991-March 1992.

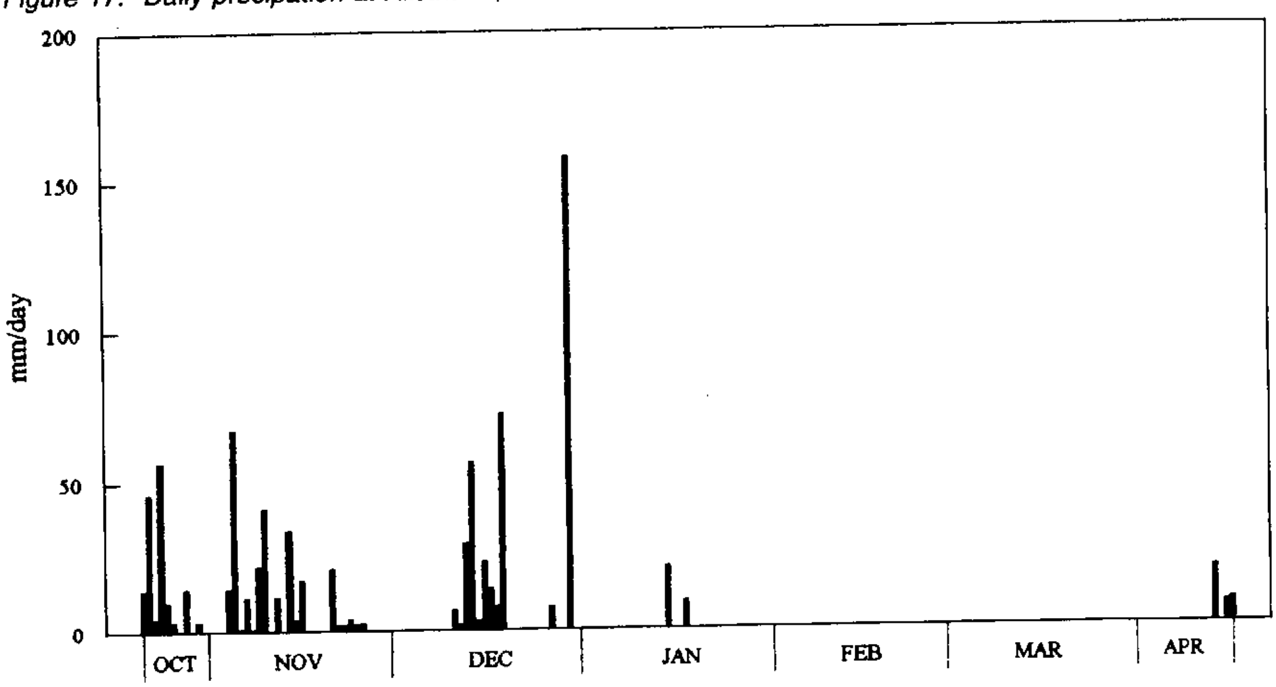


Figure 18. Daily precipation at Thirappane, October 1991-March 1992.

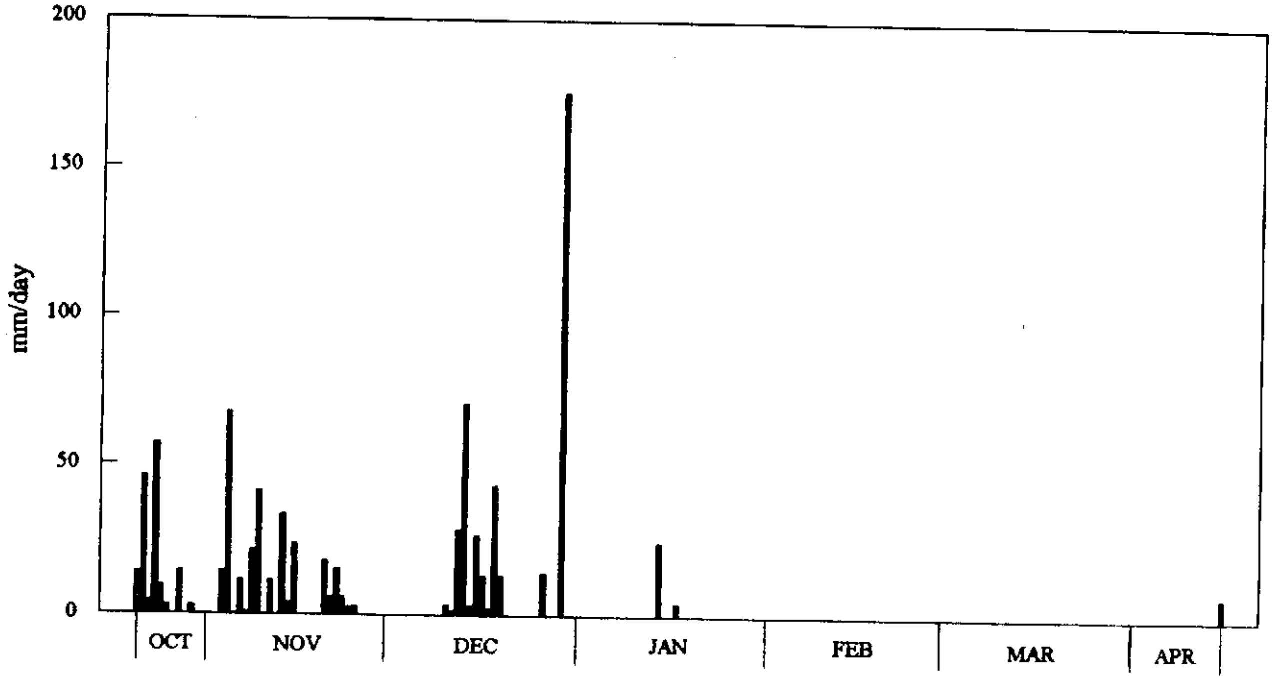
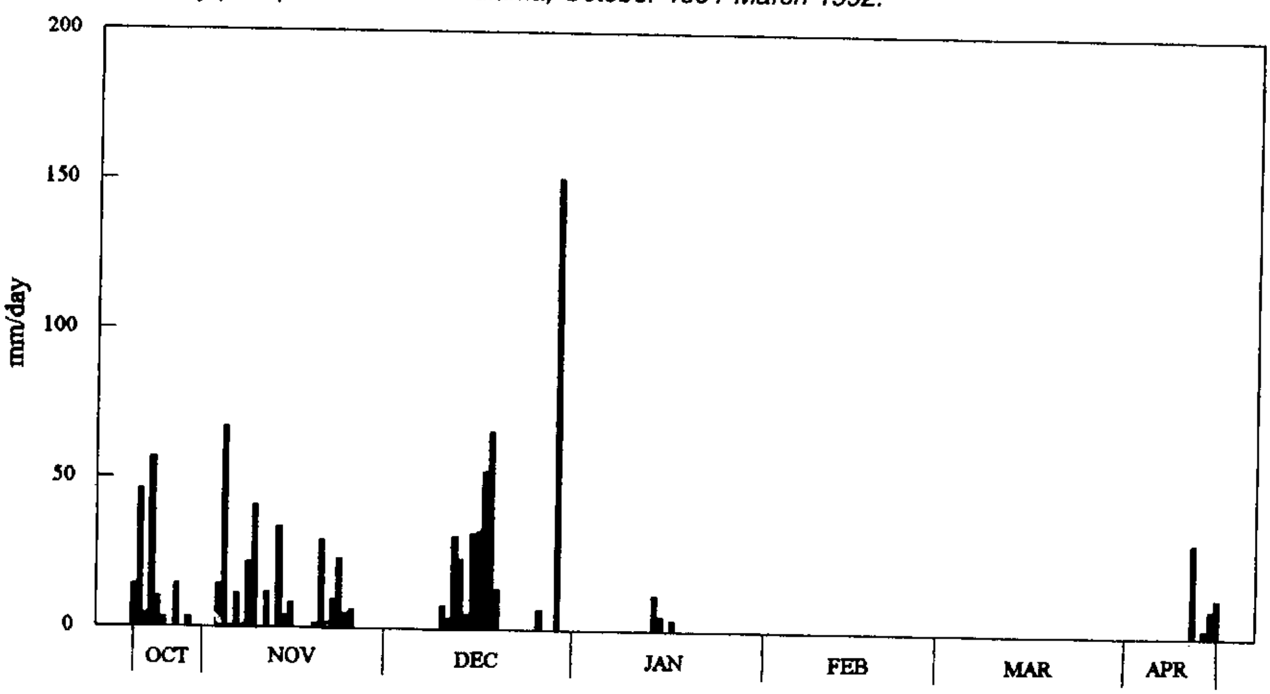


Figure 19. Daily precipation at Bulankulama, October 1991-March 1992.



Water Issues from the Tanks

Figures 20 to 25 display the fluctuations of the daily water issues from each tank gate. The intensities were based on the calibration of parshall flumes and the calculation of them by the standard flow formula. In the case of submerged flow, the values were corrected.

Figure 20. Daily water issues from Vendarankulama, November 1991-April 1992.

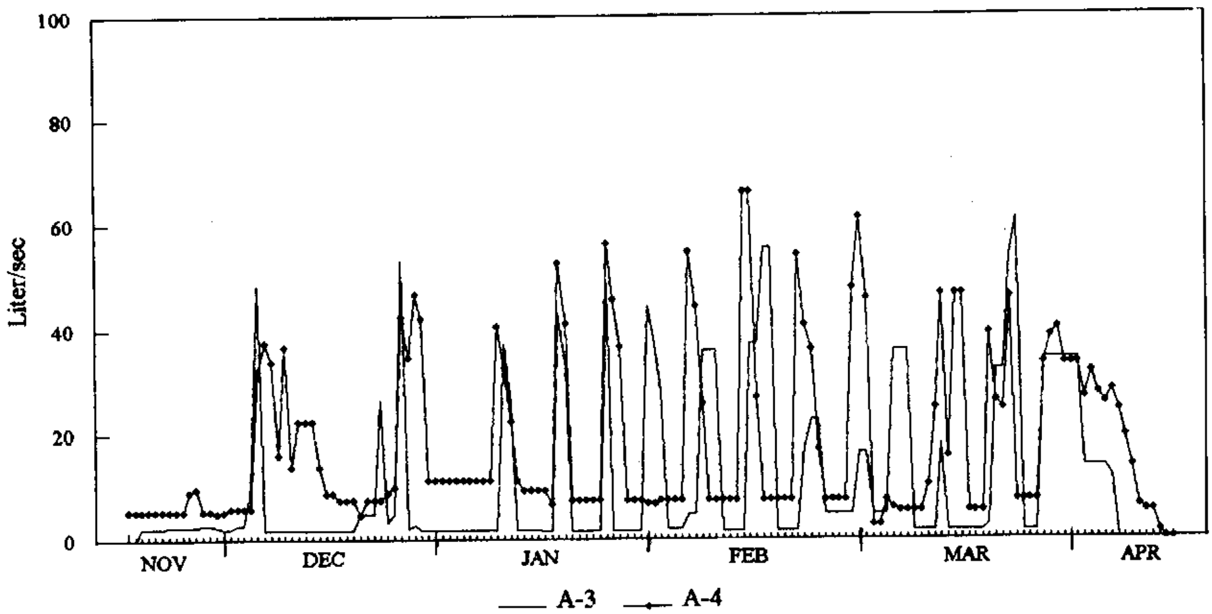


Figure 21. Daily water issues from Meegassagama 1, November 1991-April 1992.

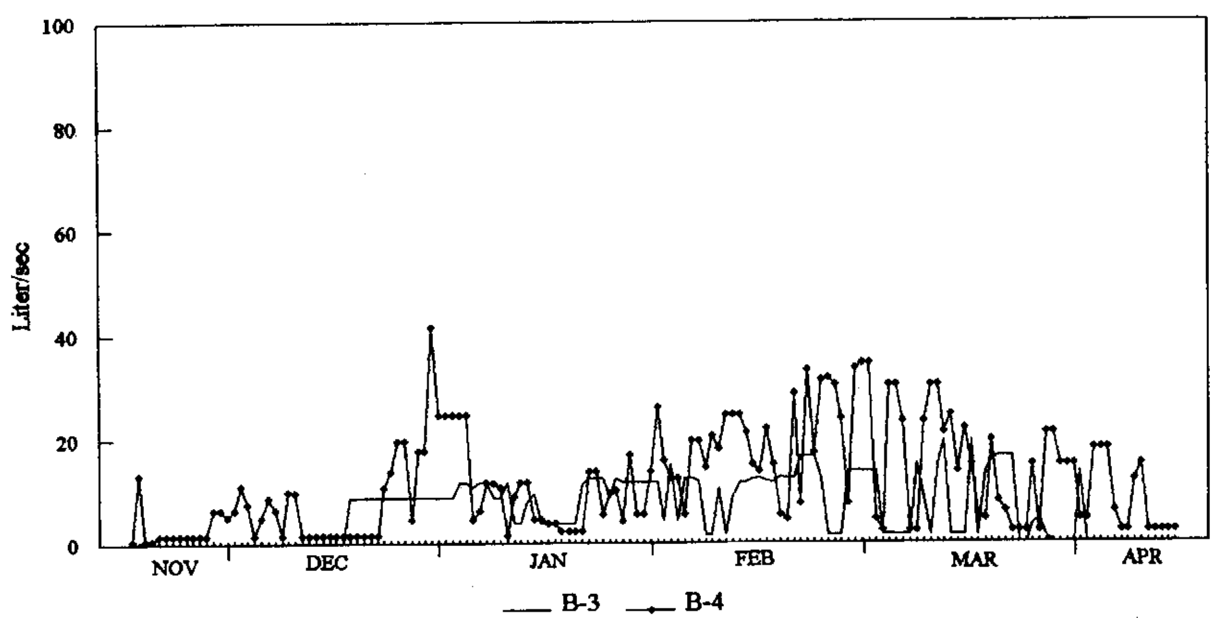


Figure 22. *Daily water issues from Meegassagama 2, November 1991-April 1992.*

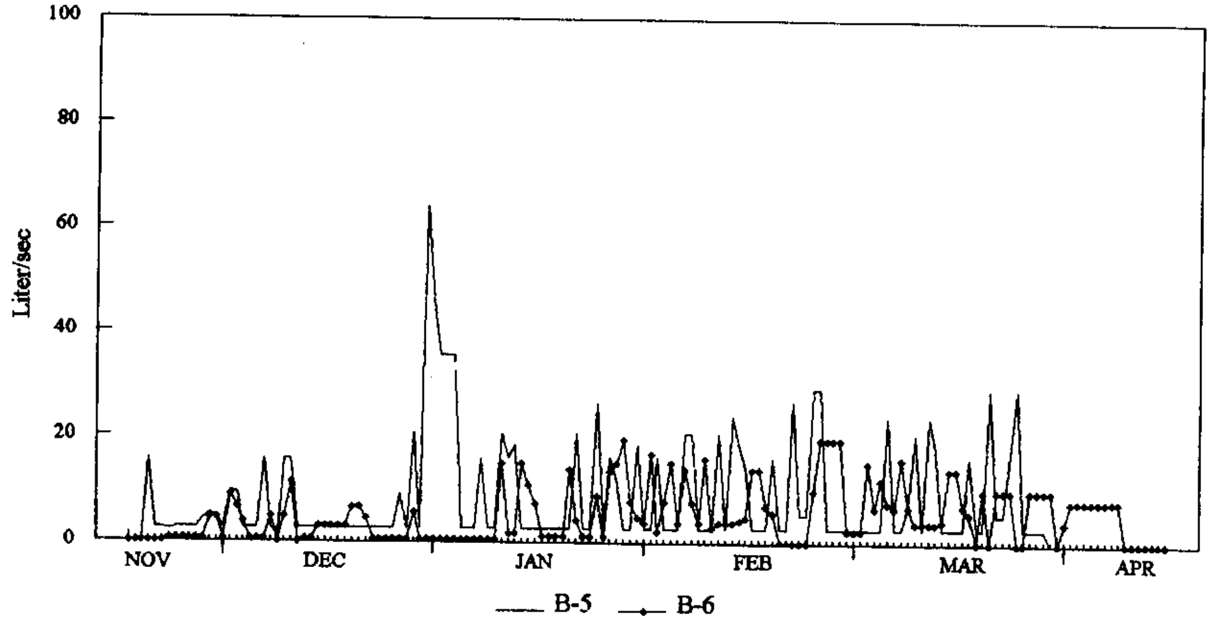
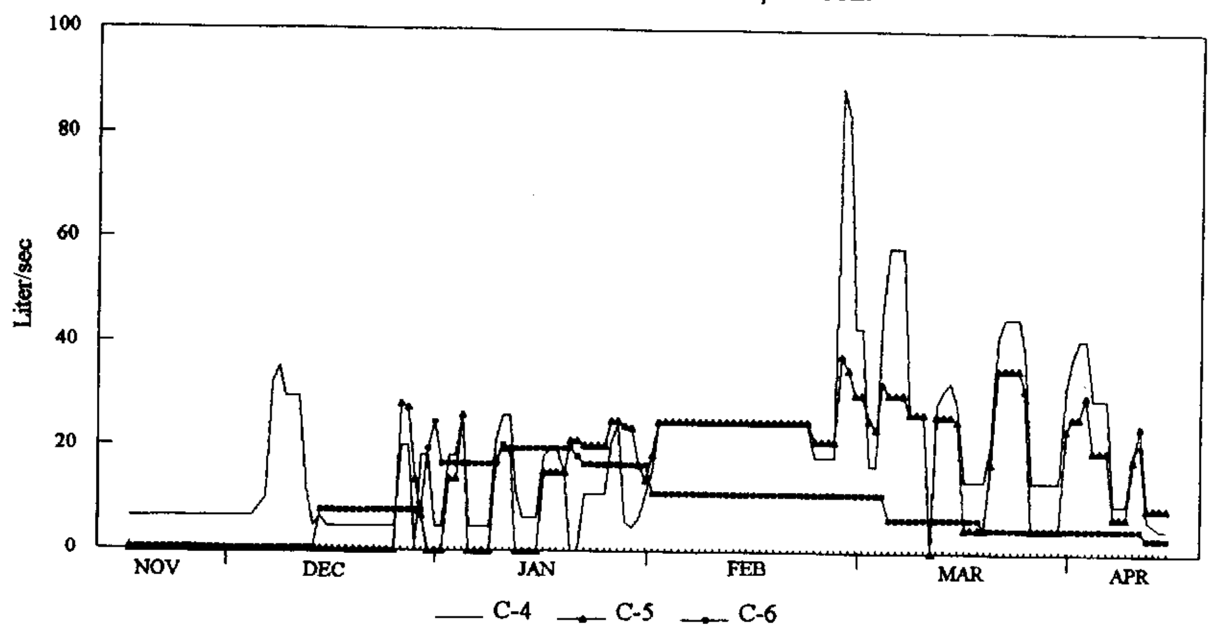


Figure 23. *Daily water issues from Alisthana, November 1991-April 1992.*



Flow rates varied quite widely, and great differences can be seen in the frequency of variation. For example, the flow rate at outlet D5 (Thirappane Tank) twice remained unchanged for a month continuously, whereas flows at all the gates at Meegassagama seem to be adjusted every two or three days. These features are further discussed below.

Figure 24. Daily water issues from Thirappane, November 1991-April 1992.

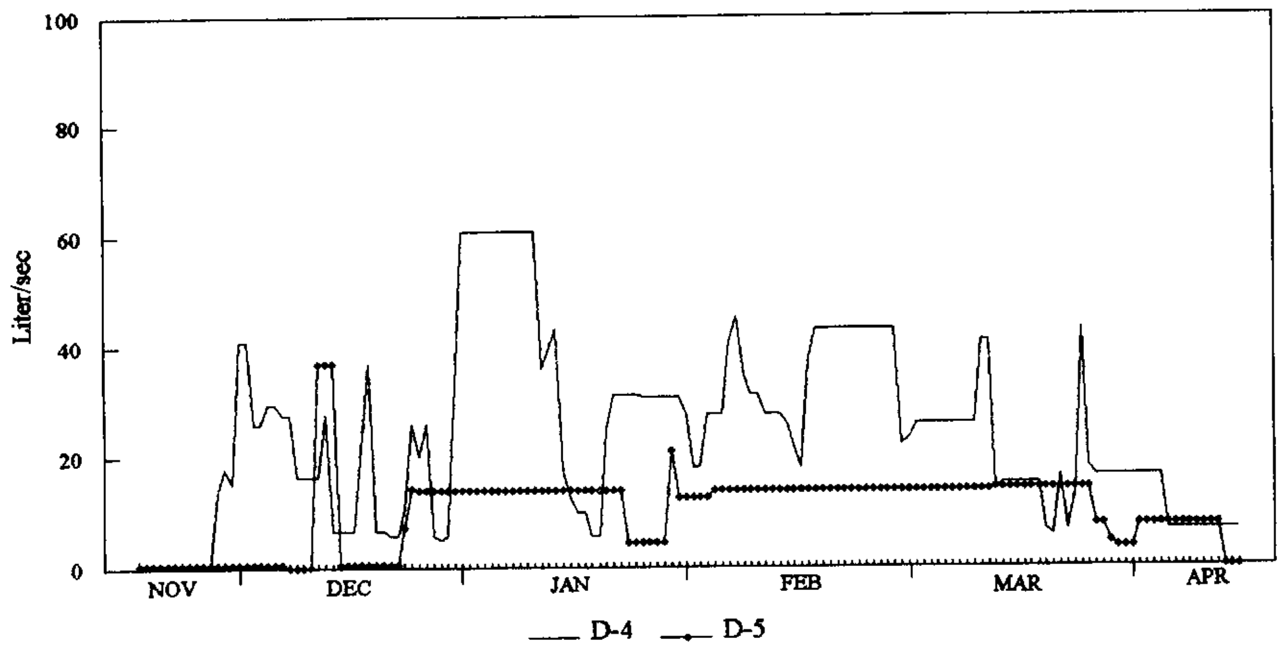


Figure 25. Daily water issues from Bulankulama, November 1991-April 1992.

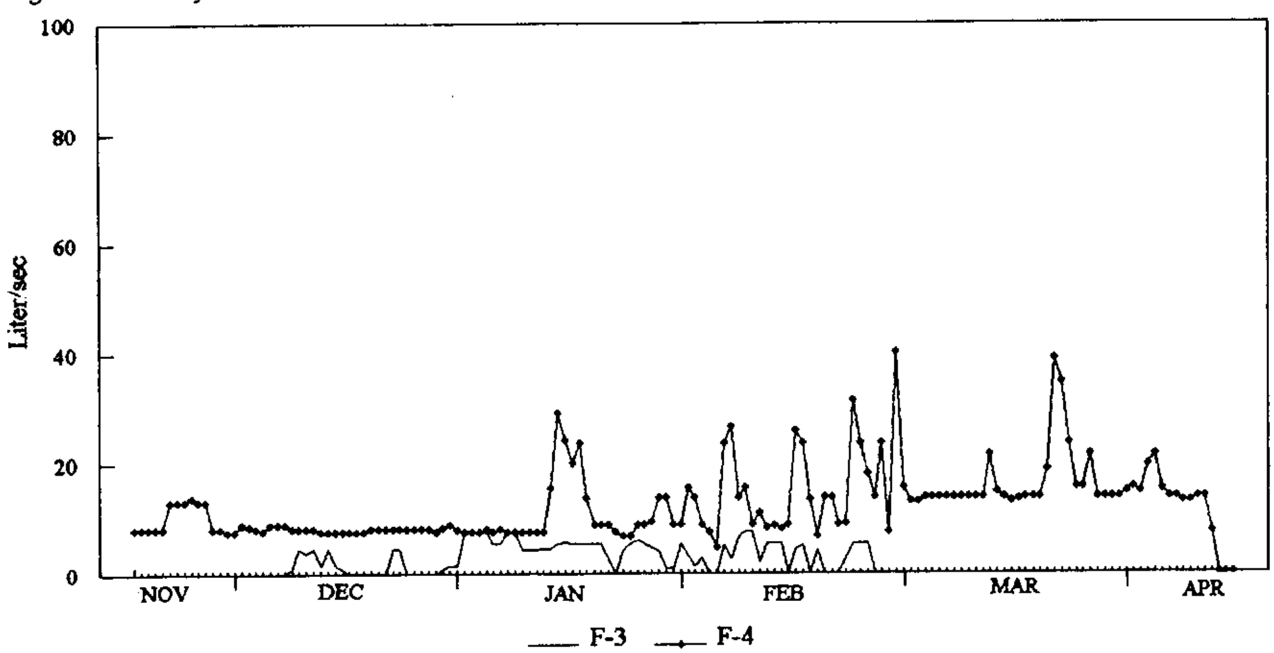


Figure 26 shows the total water issues from each tank, integrated over 10-day blocks, and Figure 27 shows the same information divided by the command area of each tank, so as to make the curves more directly comparable with each other, in terms of mm/day issued.

Figure 26. Water issues (ten-day averages), at all tanks, November 1991-March 1992.

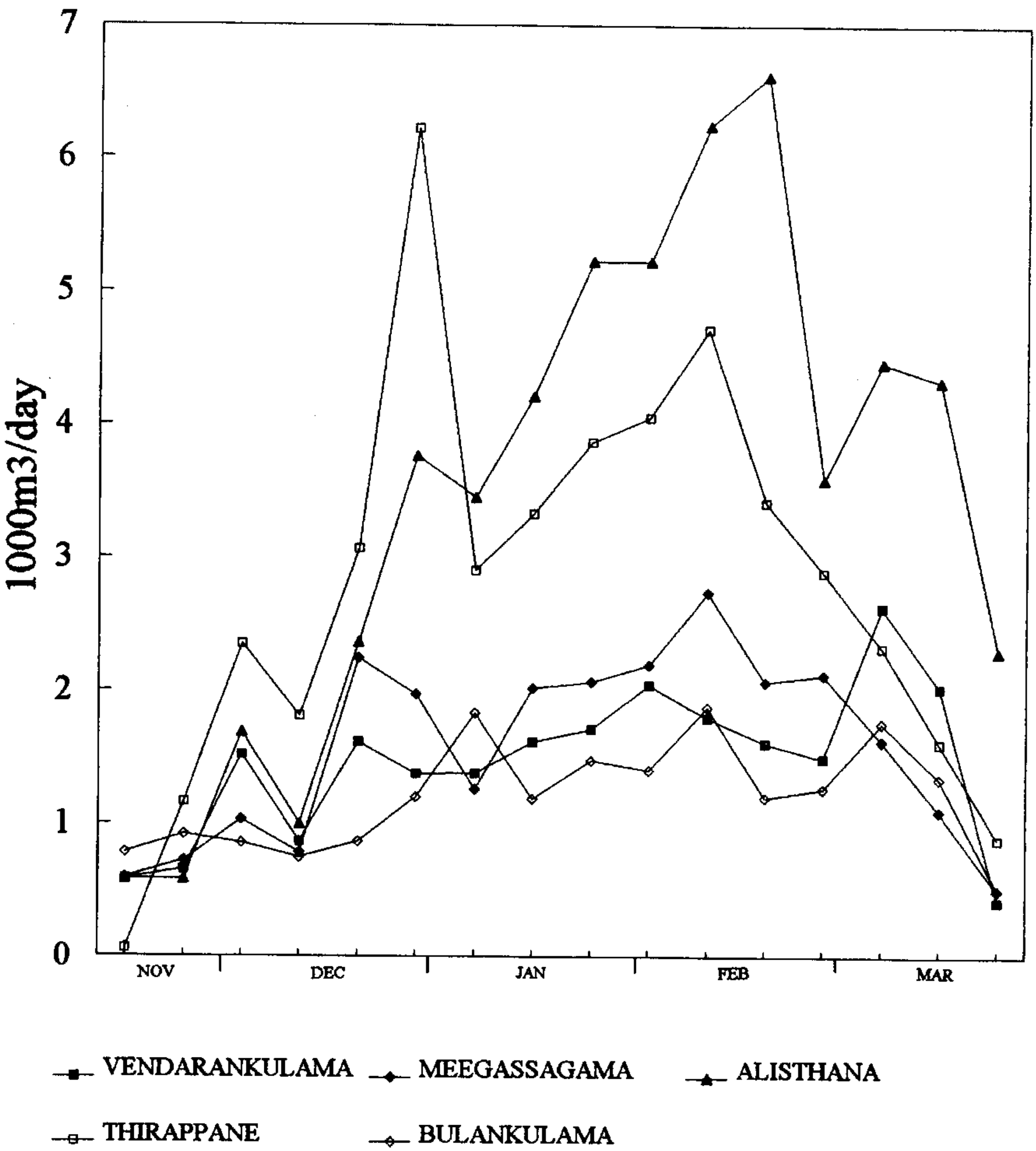
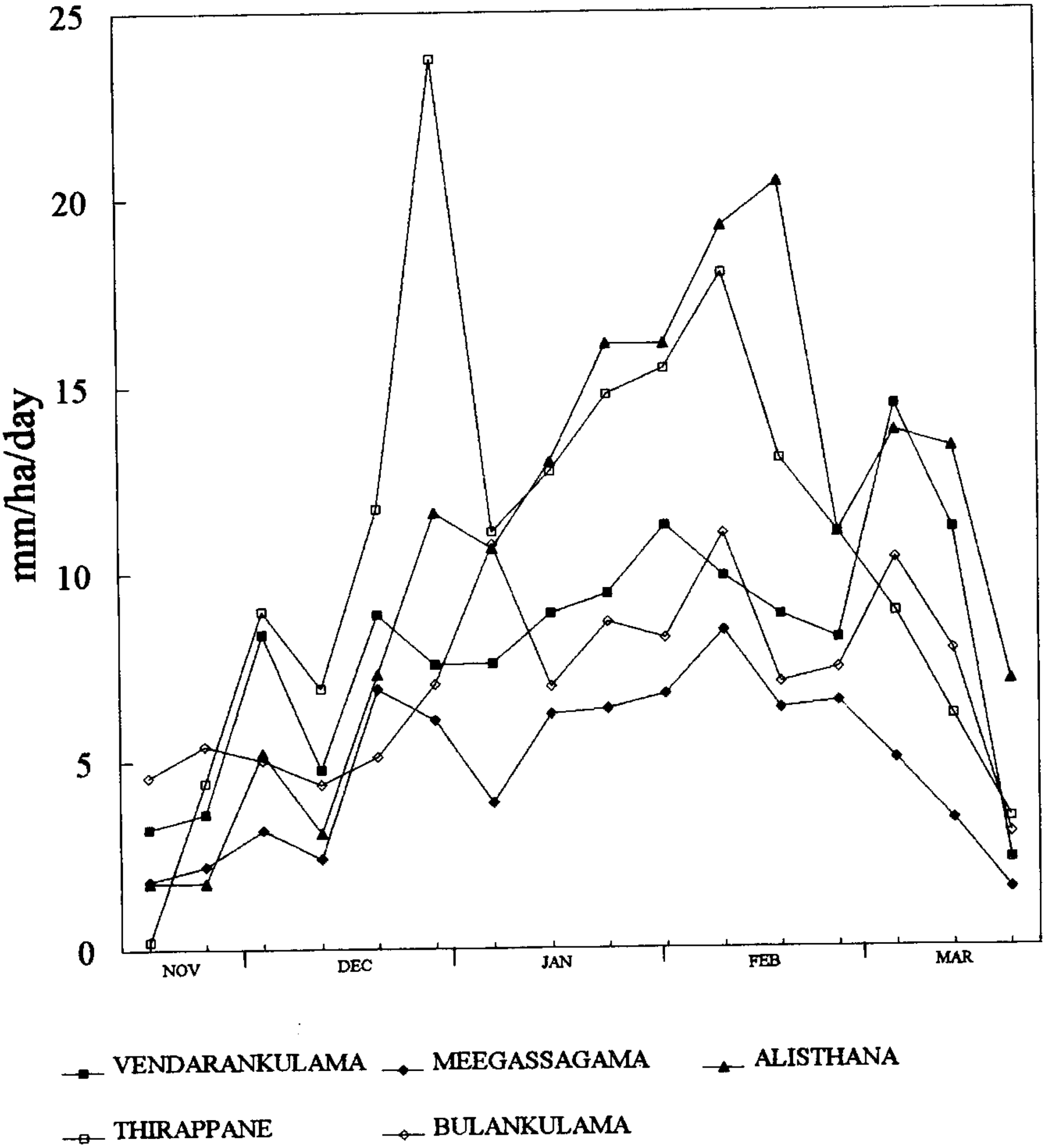


Figure 27. Water issues (ten-day averages), per hectare at all tanks, November 1991-March 1992.



Drainage Flows from the Command Areas

During maha 1991/1992 and yala 1992, drainage flow was measured by parshall flumes at the tails of the three drainage courses out of Vendarankulama/ Bulankulama, Meegassagama and Alisthana (Figure 13 on p. 22). Another one (measuring weir) was furnished in the outlet of the Thirappane block at the beginning of maha 1992/1993, because the monitoring at the spot was indispensable in order to solve the hydrological phenomena of the whole system.

Figures 28 to 30 show the curves of the daily drainage flows. Among three curves, only Vendarankulama and Bulankulama have never responded to the base drainage flow. They have responded only to large drainage flow. However, it is quite strange that no drainage water has been observable since February in spite of the large amount of tank water issue in Vendarankulama. This fact points to the probability that this drainage course could not receive all parts of the drainage flows in this measurement spot. In reality, it was often found out thereafter, that the farmers in Vendarankulama and Bulankulama occasionally blocked up the drainage with small embankments with the aim of keeping the drainage water from discharging into the downstream tank. Thus most of the drainage water could not reach the monitoring spot smoothly.

Figure 28. Daily drainage flows, Vendarankulama and Bulankulama, November 1991-March 1992.

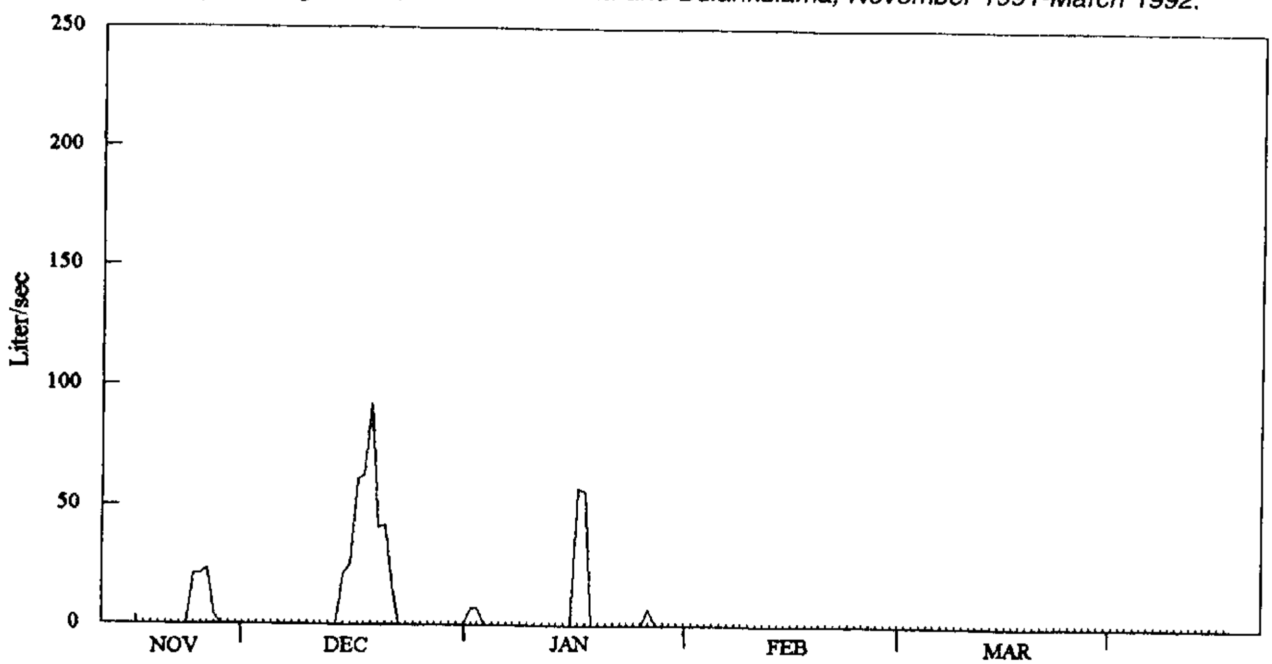


Figure 29. Daily drainage flows, Meegassagama, November 1991-March 1992.

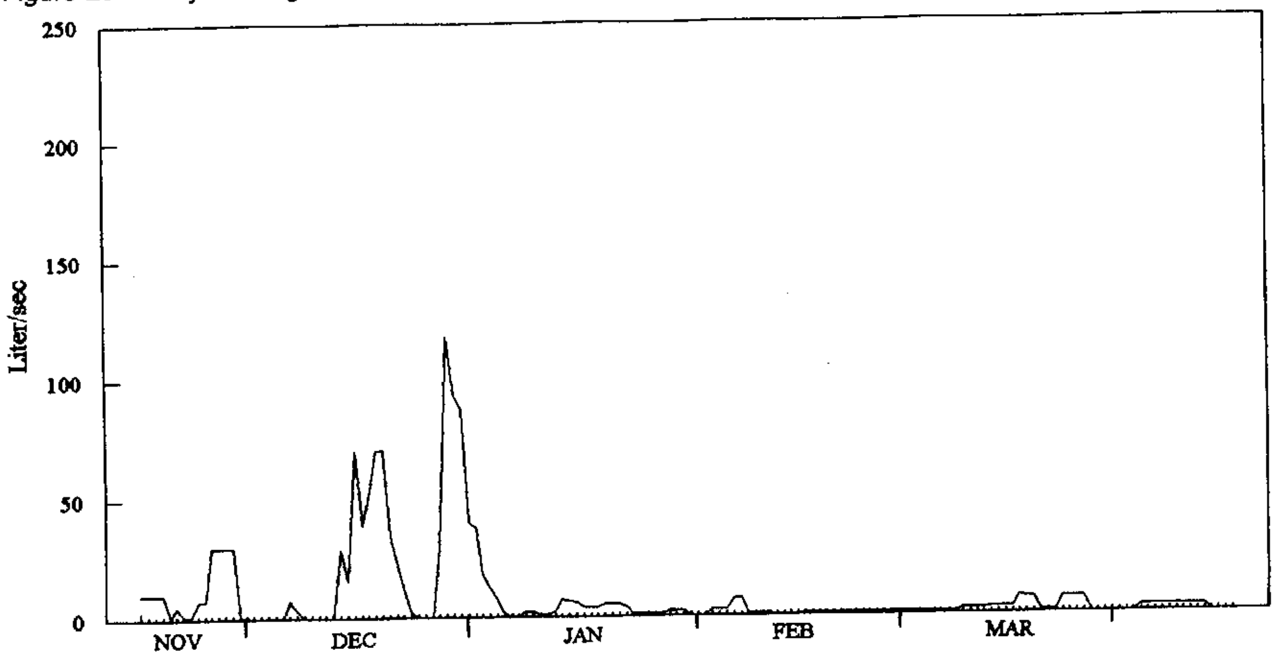
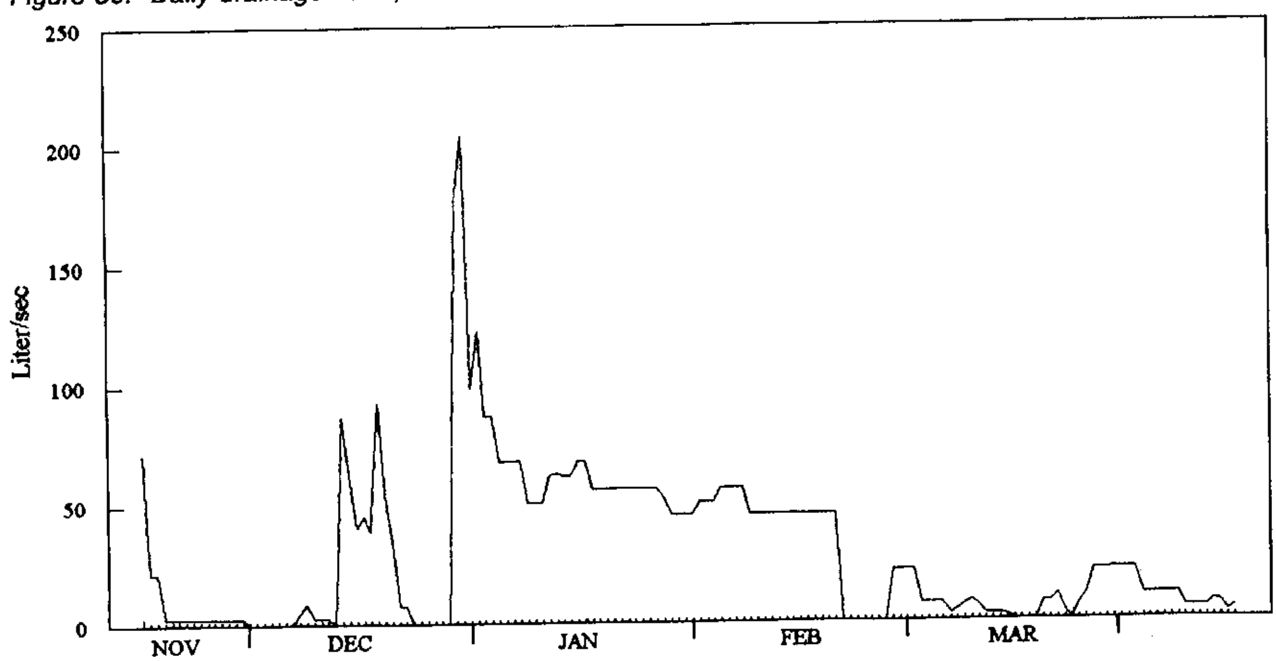


Figure 30. Daily drainage flows, Alisthana, November 1991-March 1992.



Water Level in the Tanks

Figures 31 to 37 show the curves of the water level in each tank. In this area, farmers usually commence maha irrigation by the end of November, considering the rising pace of the water storage level in the tank. However in 1991, its rising speed was slow in October and November as a result of water balance. It had therefore been impossible for some tank blocks to commence irrigation as planned. With regard to some parts of the command areas in Alisthana and Thirappane, the commencement of the water supply was delayed and started after the beginning of December. Thereafter, there was a long spell of rainfall in December and the water level reached the full-tank level finally on 29 December. Moreover, on this day, spill water due to heavy rainfall over 100 mm/day, was observed at every tank.

As a whole, throughout the 1991/1992 maha season, water management was by no means difficult for farmers because the water storage level continued to rise up till the end of December. Especially in December, its rising speed increased on account of the concentrated rainfall. At the end of December, farmers were probably convinced of the safety of the water supply at least within the rest of that maha season even though there was no rainfall thereafter. In the meantime, the total irrigable command area for the following yala season is greatly affected by the leftover tank water at the end of maha, because in yala farmers cannot expect enough rainfall. Then they are inevitably compelled to depend mostly on the tank water. Farmers therefore, are eager to restrict tank water issue in maha. In 1991/1992 maha, too, farmers acted according to this incentive.

Figure 31. Daily water levels of Vendarankulama tank, October 1991-April 1992.

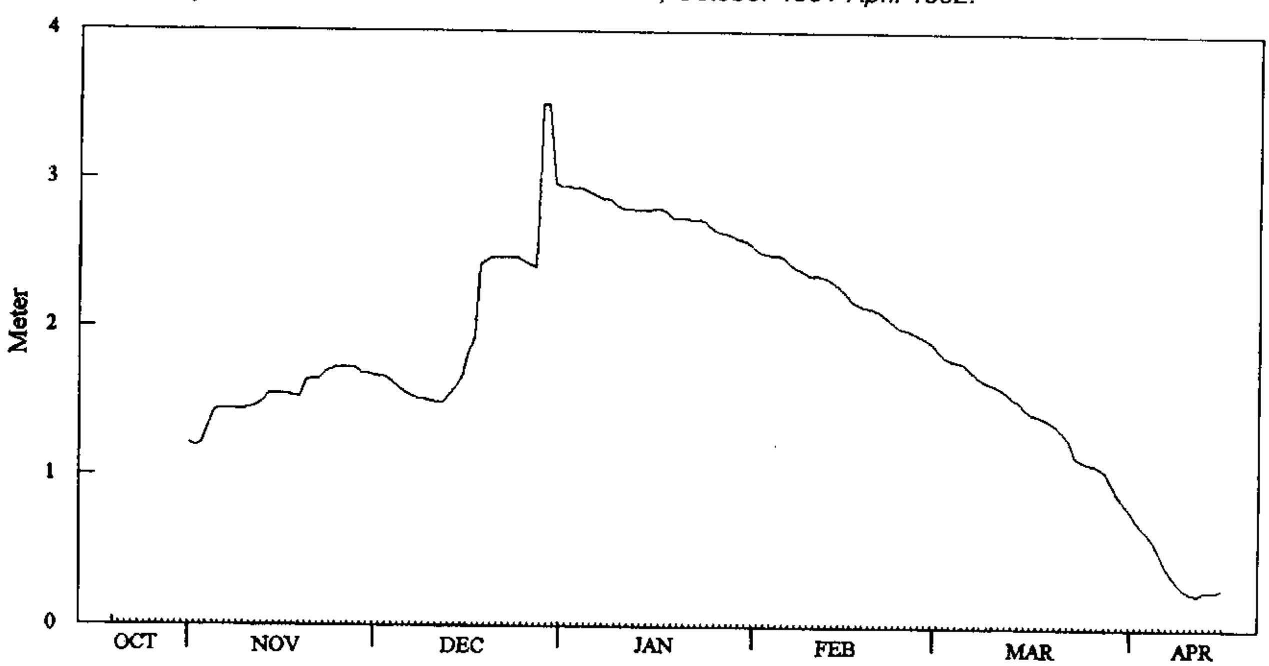


Figure 32. Daily water levels of Meegassagama tank, October 1991-April 1992.

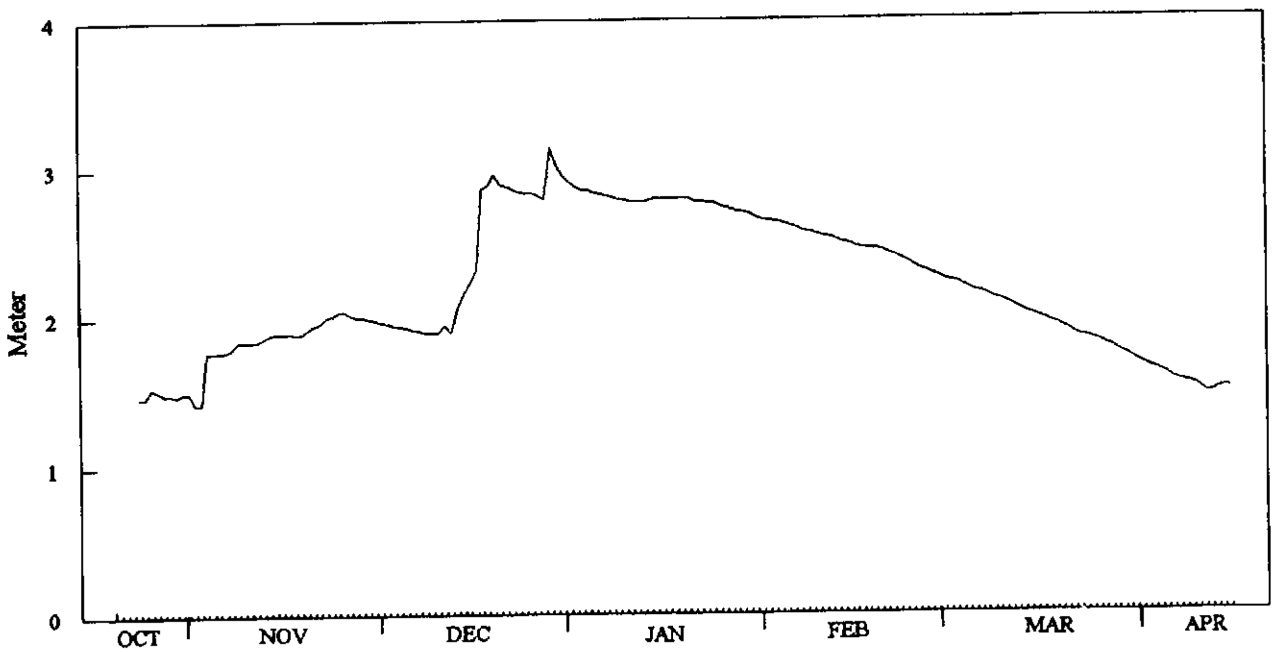


Figure 33. Daily water levels of Alisthana tank, October 1991-April 1992.

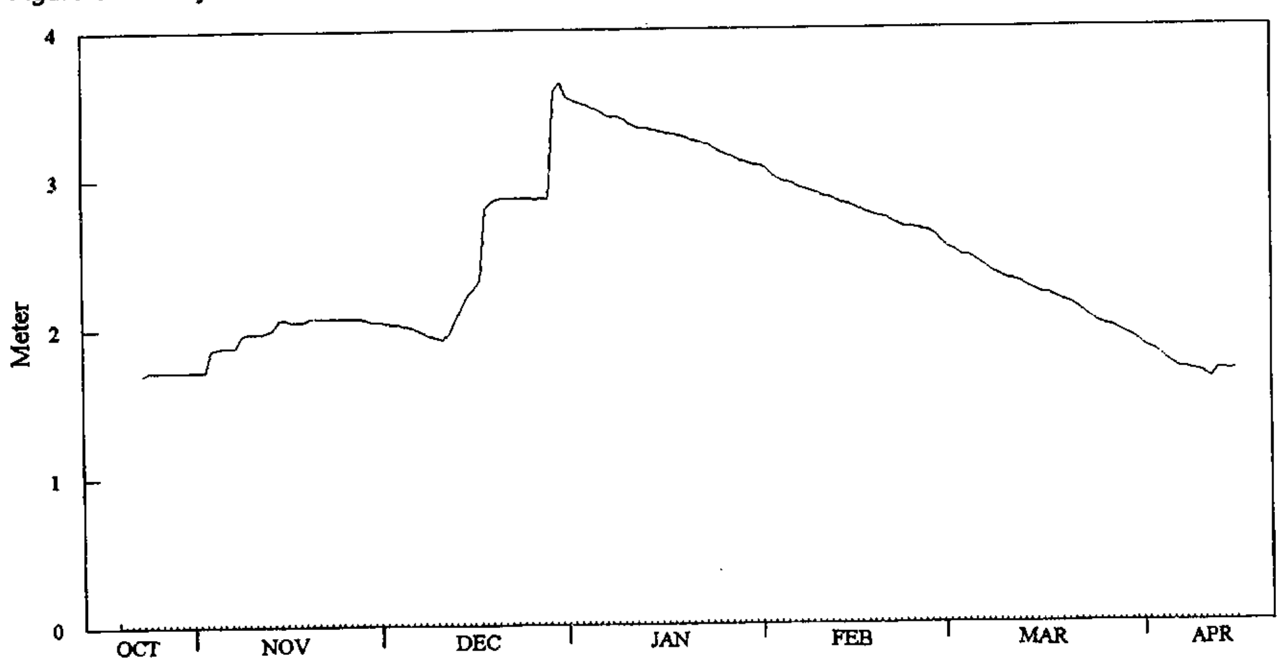


Figure 34. Daily water levels of Thirappane tank, October 1991-April 1992.

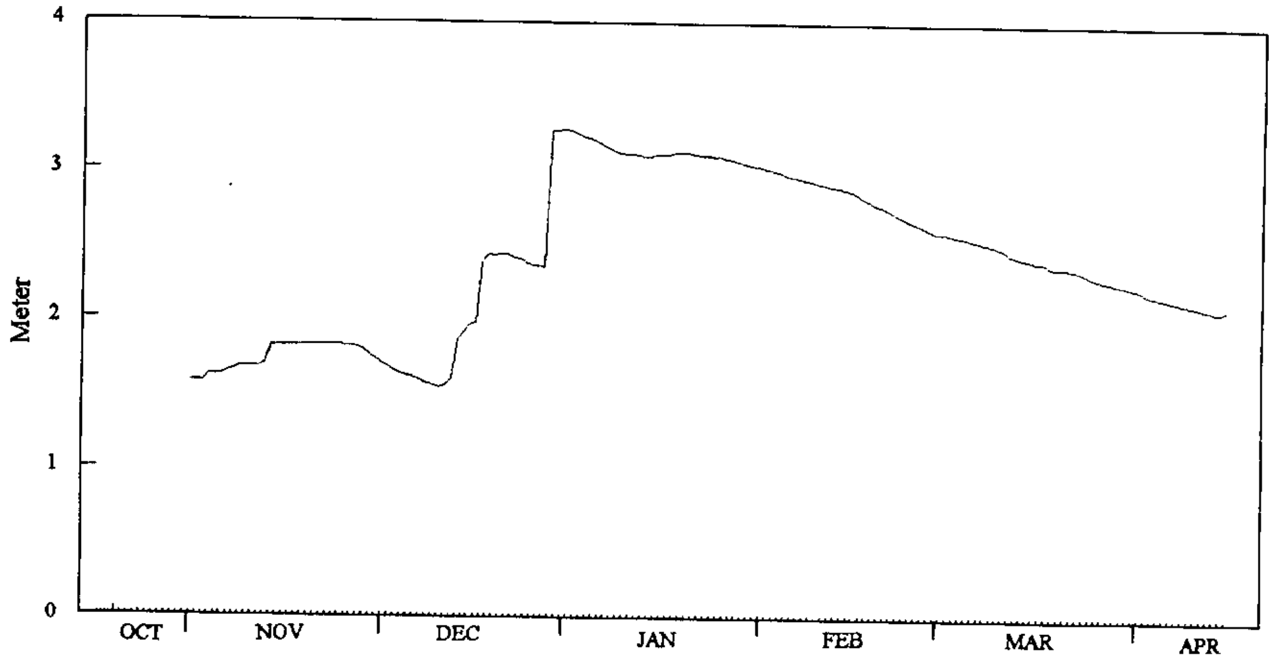


Figure 35. Daily water levels of Badugama tank, October 1991-April 1992.

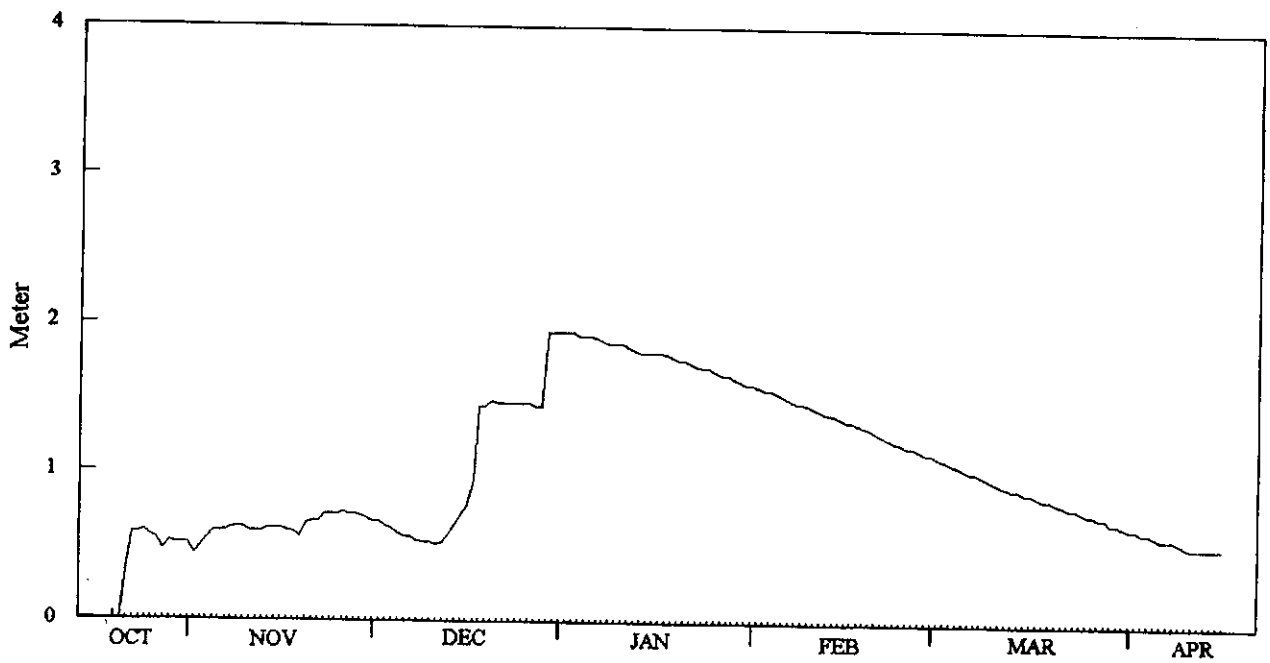
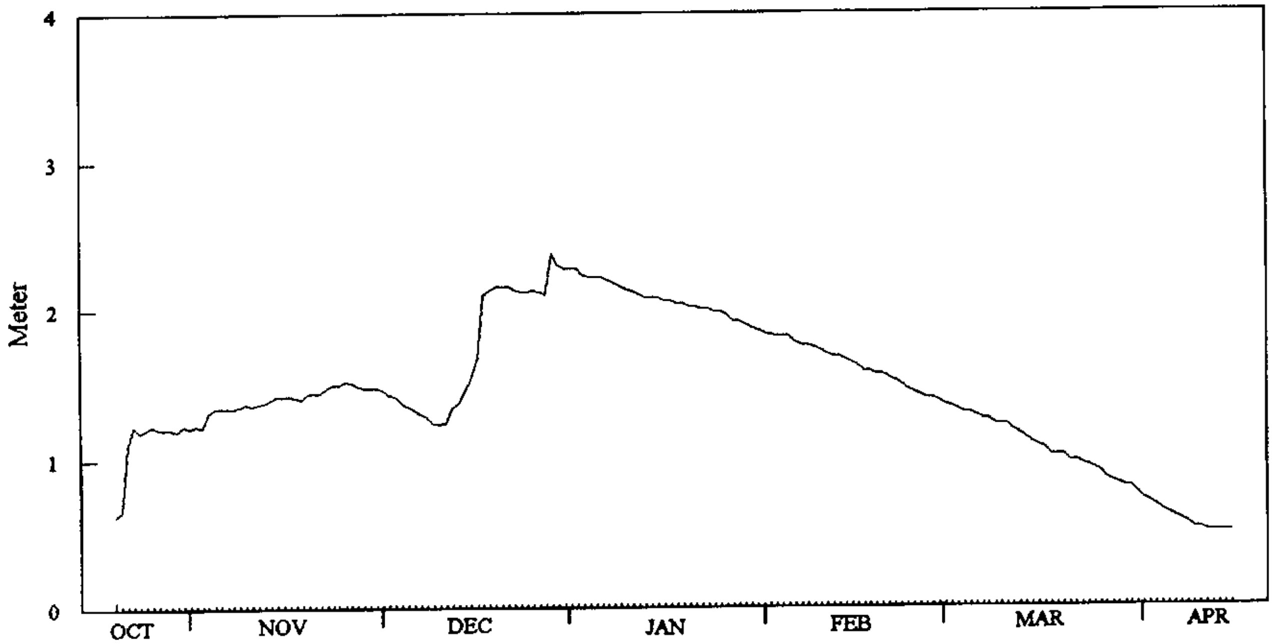


Figure 36. Daily water levels of Bulankulama tank, October 1991-April 1992.



Evaporation and Evapotranspiration

Figure 37 shows the periodical fluctuation curves of daily evaporation and daily evapotranspiration, both of which were calculated through a set of lysimeters which were installed in a rice field lot in Meegassagama. Original data collection commenced at the end of December 1991. In this graph, we can see that daily evaporation values had monotonically increased with time. As a whole, the evapotranspiration values had also monotonically increased in response to evaporation, similarly. These trends are presumed to have a strong relationship with the rainfall (Figure 38), which had hardly been observed since January.

Just for reference, Figure 39 compares the two kinds of evaporation data. One was calibrated by the standard large-scale evaporation pan which was furnished at the ground beside the Meegassagama tank bank and the other was by the lysimeter above mentioned. Both data showed similar trends. But the former constantly showed larger values than that of the latter, as was expected. This gap is assumed to be mainly due to the difference in surroundings between these two devices.

Figure 37. Evaporation and evapotranspiration, December 1991-March 1992.

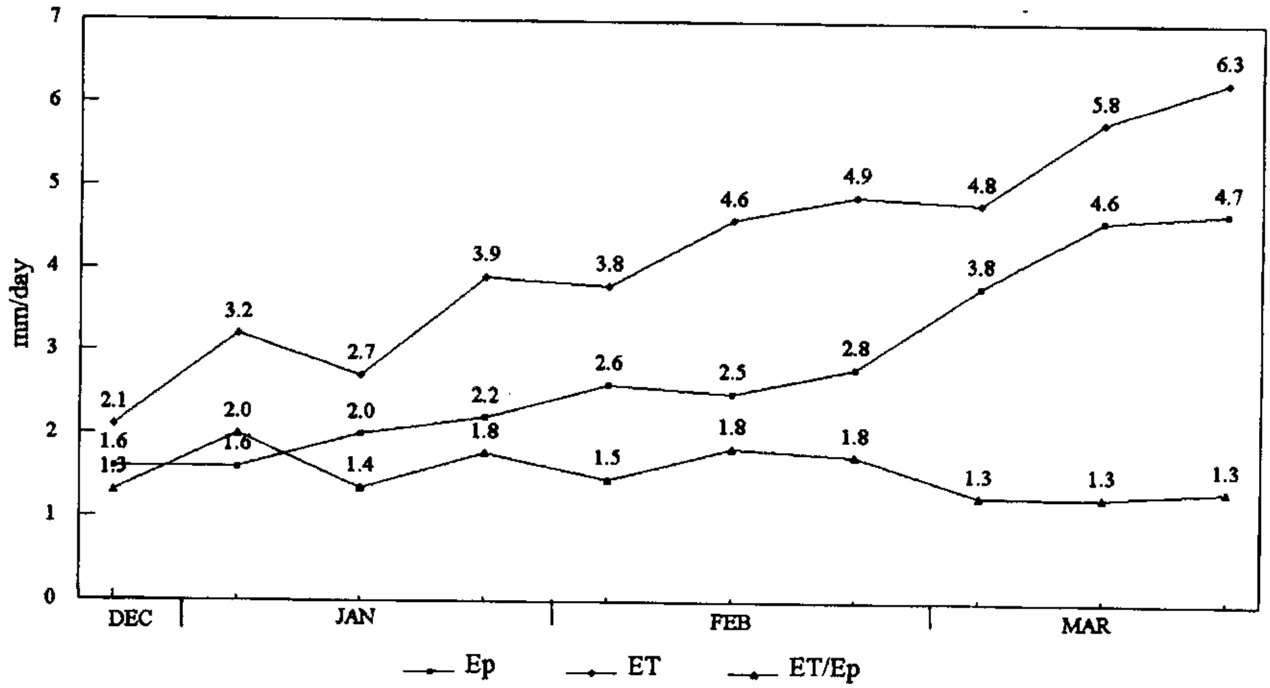


Figure 38. Precipation, December 1991-March 1992.

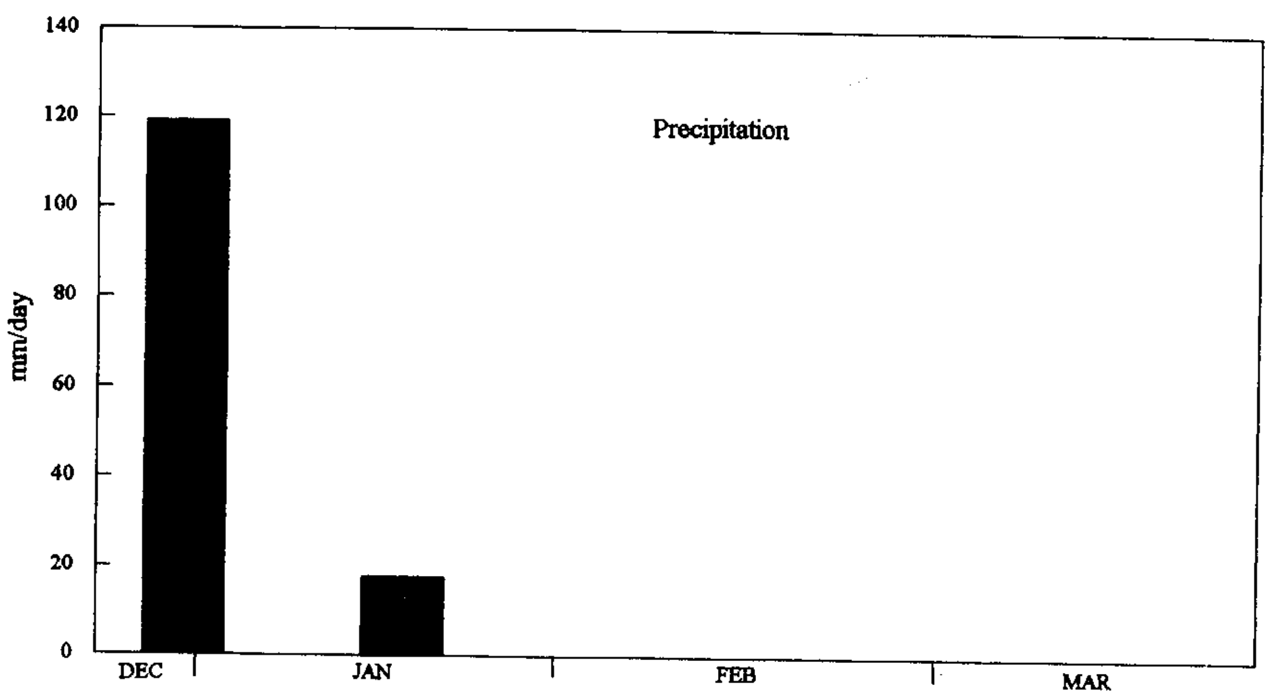
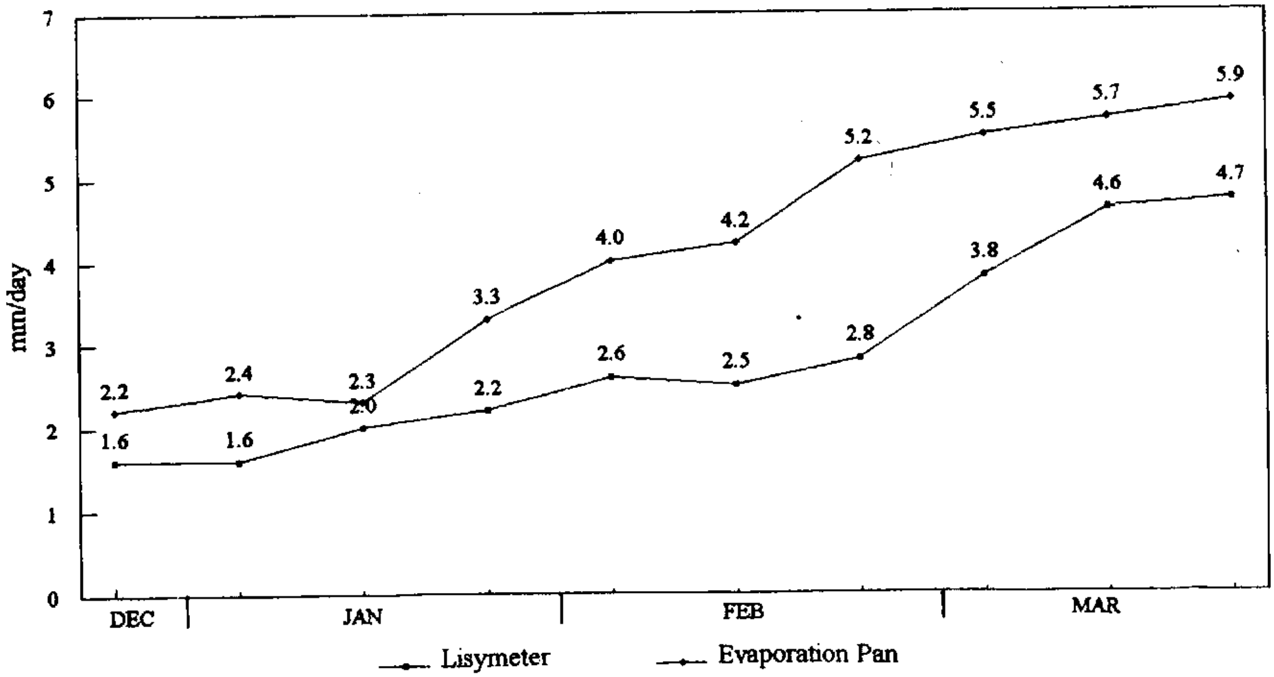


Figure 39. Comparison of lysimeter and pan evaporation measurements.



To estimate the water requirement in depth in the rice field, percolation values are also necessary in addition to evapotranspiration values. However, usually that value is greatly influenced by the underground water level in the fields, and so on. Therefore it is often difficult to get clear data of percolation. It is necessary to carry out a further season's observation to fix the percolation data.

Values of the official standard evapotranspiration (Etc) and field irrigation requirement (FIR) for rice in this region are as follows.

Table 6. Monthly value of Etc and FIR.

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Etc(mm/day)	5.1	3.9	4.3	4.6	-	-	-	5.5	6.8	6.3	-	-
FIR(mm/day)	8.5	6.6	7.1	8.0	-	-	-	9.2	11.4	10.5	-	-

* The values of FIR do not include the management water requirement.

DISCUSSION OF THE OBSERVATIONS

Water Management at the Tank Outlets

Table 7 shows data related to the average daily water supply from 15 November 1991 to 31 March 1992. In this season, tank water issue commenced at the beginning of November after the land preparation. Irrigated areas increased gradually thereafter. Although the data do not cover the first half of November, they certainly cover most of the irrigation period. Hence, we can treat these data without trouble.

Table 7. Average water issue of maha 1991/1992.

	(1)	(2)	(3)	(4)	(5)	(3)+(5)
Name of tank	Total water issue (1,000 m^3)	Issue per unit area (mm)	Average issue (mm/day)	Total rainfall (mm)	Effective rainfall (mm/day)	Average supply (mm/day)
Vendarankulama	232	1,297	10.6	396	1.9	12.5
Meegassagama	243	746	6.2	596	2.9	9.1
Alisthana	549	1,693	14.1	613	2.9	17.0
Thirappane	447	1,706	14.2	651	3.1	17.3
Bulankulama	189	1,109	9.2	680	3.3	12.5

In column 5 of Table 7, effective rainfall is estimated tentatively as 0.67 of the total rainfall that occurred during the relevant irrigation period, and divided by the total number of days in that period.

For comparison with the data in Table 7, we may also note the official assumed figures for rice crop water requirements in this area, which are shown for the months of November and January in Table 8.

Table 8. Assumed crop water requirements in Thirappane area.

		November	January
Net water required in field	mm/day	3.7	6.6
Conveyance losses	mm/day	1.0	1.7
Grosswater required from tank	mm/day	4.7	8.3

In this table, conveyance losses are estimated as 20 percent of the total water issues from the tank.

It is apparent from Table 7 (columns 2 and 3) that the performance of Meegassagama, in terms of water used, was very much better than the other tanks, and that it was the only tank whose actual water issues were in the expected ranges shown in Table 8. The daily water issues (in mm) at

Vendarankulama and Bulankulama were about 50-70 percent greater than at Meegassagama, and at Alisthana and Thirappane the issues were more than double the Meegassagama level.

Figures 20 to 25 (pp. 27-29) have already given an indication of a likely reason for this. It is apparent that at the Meegassagama outlets, gate operations occur very frequently; at Alisthana and Thirappane they occur quite seldom; and at Vendarankulama and Bulankulama gates are operated at some intermediate frequency.

In places where water is scarce, and where rainfall is small, irregular and difficult to predict, it seems reasonable to expect that farmers would take some action to try to prevent wasteful or unnecessary issues of water. Why should the different tank communities behave differently from each other in this matter? One possible reason can be found in the relative sizes of their tanks. A relatively large tank (large in comparison to the command area that it has to supply) gives the farmers a high level of water security. In these circumstances, perhaps, they may not give quite such a high priority to saving water, as would be done by a different village whose tank size is relatively small.

The above argument is not complete, however, because the size of the catchment area also may influence behaviour, and responses by the farmers. If a tank is relatively large, in relation to its command, but also in relation to its catchment area, then there will be a higher probability of years in which it fails to fill completely. So, if the contributing catchment area is relatively small, we might expect the farmers who depend on that tank to become rather sensitive to water management.

In Table 9, the tank volumes (Table 3) are combined with irrigated areas (Table 1) and catchment areas (Table 2) to form two ratios, volume/irrigated area and volume/catchment area.

Table 9. Relative sizes of tanks.

	Tank volume (V) (1,000 m^3)	Irrigated area (A) (ha)	Catchment area (C) (Km^2)	V/A (m)	V/C (m)
Vendarankulama	220	18.2	1.95	1.21	0.113
Meegassagama	360	32.5	3.56	1.11	0.101
Alisthana	580	32.4	3.70	1.79	0.157
Thirappane	790	26.2	4.48	3.01	0.176
Badugama	80	1.1	0.26	7.27	0.308
Bulankulama	100	17.1	0.64	0.58	0.156

It seems reasonable to use the characteristics of the canal flow curves (Figures 20-25 on pp. 27-29), especially their frequency of changes, as an indicator of the attentiveness of the farmers to gate operation, and hence, the priority that they give to the objective of restraining wasteful issues of tank water.

Table 9 seems to suggest at least a partial explanation of the observed behaviour. Meegassagama, where the gate operations were most frequent and the attention to water-saving highest, has the smallest of the four principal tanks, according to the volume/irrigated area (V/A) ratio in Table 9. On the other hand, at Thirappane, where the water security level represented by V/A is 2.7 times as high as at Meegassagama, gates may remain unadjusted for a month at a time, because apparently, water saving does not get high priority.

The frequency of operations at Bulankulama was less, even though the tank there is very small. However, this tank has only the "tower-type" outlet, not an adjustable sluice, so the water control opportunities cannot be compared directly with the four larger tanks.

In general, comparison of Figures 20 to 25 (pp. 27-29) with Table 9 seems to confirm that the ratio V/A has an influence on the farmers' behaviour and attention to water control.

Figures 26-27 (pp. 30-31) support this. Figure 27 shows the water issues to each tank command area, in 10-day periods throughout the season. In almost every period, water issues at Meegassagama were the lowest among the five tank command areas studied in this way.

Throughout the cascade, the rainfall pattern does not vary much (Table 5), and soil types and unit field water requirements are also probably almost equal. In addition, it seems needless to say that every tank block has strong reasons to achieve water saving. There are however great differences in the water issues from the tanks, which may be attributed to differences in the attention given to water management by the different communities.

The communities which, at present, show lower activity on water management (Alisthana and Thirappane) are also the ones, according to Table 2, which are not currently using all of their nominal command area (79.6%, compared with 100.0% at the other principal tanks). The reasons why there may be some loss of motivation with regard to both land and water management at these two tanks may be explored under the project's socioeconomic component.

Water Conveyance Losses

The scale of this tank cascade irrigation system is rather small. It is only about an 8 km distance from the head-end tank to the tail-end one. In addition, it is divided into six small tank blocks. Every tank block manages an independent tank irrigation system composed of a compact command area and a primitive canal network. Head races are very short, too. However, land improvement works have not been applied, and most of the tank blocks are still depending on unclear and disorderly irrigation systems. In some cases, partially damaged canals and wrong canal slopes have been left in place and have caused conveyance disorder. Under such poor physical conditions, it is difficult to implement water conveyance without waste. Among the respective tank blocks, only Meegassagama's conveyance loss is supposed to have been comparatively low because of its more systematic canal network. On the other hand, the losses of other tank blocks are thought to have been high. Their high conveyance loss seemed to be reflected in the average amount of the tank water issue. However, in this area, improvements of the water conveyance are thought to be easy because of the short length of the canals.

System-Level Water Management

a. *Daily water management.* In this system, every command area is located just downstream of the tank site. The size of each command area is rather compact (less than 40 ha). Therefore, the system operator can manage the tank water issue by looking around the water condition in both the tank and the command area simultaneously. In addition, he is a representative of the water users as well as a system operator and can easily keep in touch with other users. Therefore, first there ought to be effective communication between the water supplier's side and the water users' side. A unique circumstance like this makes daily system management easier, namely, the system operator can easily control the mismatch between tank water issue and water demand in the command area. In the meantime, unlike in the large-scale flow-type irrigation systems, the time lag of water running never causes big problems owing to the short water conveyance distance. Hence, if a tank block has a rational water delivery system and a well-trained system operator, it can easily respond to the water demand fluctuations caused by various factors, such as abrupt rainfall. In these cases, for saving tank water, the operator will control the tank water issue rapidly. Although the water demand in rice fields vary frequently over a season, a tank-based small irrigation system has high potentialities to cope with. Furthermore, owing to the compactness of the system, it is very easy for system operators to access their tanks. Therefore, if the operator is diligent, he will patrol the tank several times a day for supervision and will try to check the occurrence of wasteful water issue.

b. *Long-term water management.* For the operators, water level is the most simple but the most reliable index for implementing long-term water management. Stationary state storage water is very easy to perceive for farmer operators. Even though they have no measurement device such as a staff gauge, by experience, they can roughly estimate the fluctuation of tank water level by eye and can reflect it to water management. However, the problem is that they cannot estimate the long-term prospect of the volume of inflow into the tank, which is composed of runoff discharge and return-flow. Therefore, at present, they cannot plan long-term water management. As to daily water management, the objective of it is only to reduce the wasteful water issue. Because of some inherently favourable conditions as described above, at least daily management seems to be easily improved if the hardware are improved. However, long-term water management will never be possible without the solution of the hydrological mechanism.

In the 1991/1992 maha season, as Table 7 shows, a systematic irrigation system such as the Meegassagama block, could actually reduce the total water issue per unit area. Water management and hardware condition are closely linked. Hence, to make full use of the above-mentioned merits of the tank cascade irrigation system further and to minimize the wasteful water issue by proper daily management, improvement of the hardware is important. However, to minimize the wasteful water issue and to use irrigation water more effectively, the technology for long-term water management is indispensable nowadays.

On-Farm Water Management

To save tank water at farm level, industrious operators strive to arrest wasteful water through proper on-farm water management. Needless to say, a smoothly practiced rotational and intermittent water supply is the precondition for on-farm water management. In this case, according to the rotational plan, the system operator tries to lead the minimum water from the head inlet of the ranging field plots

(Figure 11 on p. 16). If any excessive water is found out or is expected due to rainfall, etc., in the field plots, he will control the inlet rapidly. In such a case, wasteful water seldom discharges into the drainage through the outlet of the tail-end plot.

Linkage Between On-Farm Management And System-Level Management

In the above case, the operator is requested to control both the related canal intake and the related tank gate, in response to on-farm water management. Thus, on-farm and system-level water management have to be closely linked. For this purpose, both highly skilled operators and a rational irrigation system are necessary.

At a well-formed and well-managed tank block such as Meegassagama, a severely controlled drainage flow can be seen (Figure 27 on p. 31). As Table 7 shows, in this case, average daily tank water issues (6.2 mm/day) are becoming smaller due to the restricted operational losses.

Low Percolation

Probably the most influential factor of the low value of water consumption in this area is the low permeability of the soil predominant in this area. The official standard percolation rate of rice fields in this area is approximately 3 mm/day. In the case of a high permeable soil condition, percolation usually occupies a large percentage of the net water requirement of the rice field. However, under the Low-humic Gley Soils which are predominant in the lowlands of this area, it can potentially manage with a small water supply.

POSSIBLE IMPROVEMENTS OF THE SYSTEM

The values of average daily tank water issue of the respective tank blocks were in the range of 6 to 14 mm/day in maha 1991/1992. Probably 6 mm/day in Meegassagama is almost the lower limit under the actual state. In contrast, the values of Thirappane and Alisthana (14 mm/day) are regarded as extremely high values compared not only with Meegassagama but also with the official standard value (5-8 mm/day). It seems that there is still ample room for individual tank blocks to improve in terms of both hardware and water management. Judging from one season's analyses of the water management in the Thirappane area, the following suggestions are made for possible improvement of the tank cascade irrigation system.

Hardware Improvement

a. *Promotion of farmland improvement.* For the further improvement of water management, improvement of the physical condition of the irrigation system is a precondition. Especially the reform of the irrigation and drainage network is necessary to enhance the water conveyance efficiency because the functional disorder of the canal system is often the bottleneck on water use. In the meantime, land readjustment work will enhance not only the land and labor productivity but also the efficiency of on-farm water management, such as proper rotational and intermittent water supply, and drainage control. Radical reform of the canal network usually requires farmland consolidation work.

However, such work often needs a substantial budget. Hence, in order to promote this work more economically and to apply it to as many areas as possible, it should be carried out step by step. It is not financially wise to aim at a high physical standard for each of the systems from the first phase. Unit project cost should be held down in the first step. High grade hardware is not always necessary to attain the main objective, namely, removal of the bottleneck concerning water management. Following the historical development process of the irrigation systems, further investment in the future, which may possibly aim at independent on-farm water management in each individual field lot, should be practiced only after obtaining enough benefits by the initial investment. Application of that kind of irrigation system is very useful to boost land and labor productivity. However, it should be promoted carefully in areas suffering from water shortage, because free water management may make water consumption increase, unless there is proper daily water management.

In this area, a farmland consolidation project has not been applied yet. However, with regard to the Meegassagama block, farmers have already furnished a relatively systematic irrigation system voluntarily. Their physical system is not high-grade, and there is neither lined canal nor up-to-date gates in their system. Nevertheless, they have practically succeeded at least in the elimination of the bottleneck on water management and arrested over-supply.

b. *Reform of village tanks.* Reform of village tanks is also one of the key components in the intensification of water management. Water seepage loss from the tank or water leakage loss through tank gates are mainly due to the physical condition of the tank (gate) and cannot be removed by management actions. Figures 15 to 19 (pp. 24-26) suggests that quantitative percentages of water leakage are remarkably high in this area except at Meegassagama. Needless to say, most of the leakage water on the nonwater-supply day is not directly beneficial to the irrigation system (however, it may possibly be available for the downstream tank block as return-flow).

Meegassagama owes its low value of leakage water mainly to the tank rehabilitation project completed in 1991. With this project, both the body of the bund tank and some outlet gates were rehabilitated simultaneously. Although there may still be a small amount of leakage water, one should rather evaluate the effect from this project positively than find fault with it.

In the meantime, the order of priority of the application of this project should be decided considering the hydrological linkages among the respective tank blocks. For the purpose of enhancing project effect, it is effective to give the first preference to the tank which plays a key role or is a bottleneck on water management within the whole cascade system.

c. *Reconsideration of system configuration.* Originally, the structure of an irrigation system was by no means designed based on hydrology. However, the system could function without trouble before the over-exploitation of the entire watershed took place. What made the situation worse thereafter is the fact that, with time, the structures of irrigation systems were transformed by the increase in tank density, expansion of farmlands, decrease of forest area, and so on. In addition, it is often pointed out today that, as regulating reservoirs, although some tanks in a whole tank cascade system formerly did not hold command areas in order to keep the function for maintaining sustainability of irrigation in the overall system, their transformation into ordinary irrigation tanks often disrupted this advantage. Today there is even a probability that a lot of tank cascade irrigation systems exist with serious hydrological contradictions inherent in them, which probably have bad influences on water management, although farmers may not be aware of this. Taking advantage of the opportunity of tank rehabilitation, the validity of the configuration of a complete tank cascade irrigation system should be diagnosed.

Management Technology

a. *Management of each component.* As an interim report, this paper has this far mainly surveyed water management activities in each component (each individual tank irrigation system) of a tank cascade irrigation system. Today, the main objective of management is limited only to "tank water saving." For this purpose, most of the system operators have blindly devoted themselves to daily water management. As stated above, only the Meegassagama block appeared successful in this. However, long-term water management in each component has not been carried out yet. As a result of this, the storage volume of the tank water is completely uncontrollable, and therefore the farmers may misjudge the seasonal irrigable area. Difficulties in setting up long-term water-use plans are caused by the lack of hydrological information and the lack of technologies to reflect them to the actual management plan, and moreover, by the weak constitution of the farmers' organization for implementing the action plan. This constitutional weakness is symbolized by the irregularity of the farmlands, existence of illegal settlements, and so on.

Because of many pending problems of respective components, up to now, most of the studies on the small-scale tank irrigation system have concentrated only on each component. As a result the importance of improving the performance of the system as a whole has been disregarded, and the viewpoint of the management of the tank cascade irrigation system has not been taken seriously. Lacking an overall management plan, each component could not have grounds for long-term management. In this situation, what we must be careful about today is to maintain broad perspectives regarding land and water use and to notice the gradual, latent deterioration in the stability of the whole system due to the slow but continuous change of hydrological phenomena within the watershed.

b. *Management of the overall system.* Water management of the overall system aims at optimal water use as a whole system. For that purpose, setting up an integrated water management plan, which may possibly involve the re-formation of the configuration of a whole system as well, is required. Compared with simple diagnoses of the physical problems individual irrigation facilities have, detection of the structural defects of an overall irrigation system is much more difficult but is more important from a broader point of view. However, the problem is that today, there is no system by which to assess the structural validity of an existing tank cascade irrigation system and to connect it to the long-term management plan. Area-wide water balance simulation based on a numerical model is one of the applicable methods by which to approach this issue. In applying it, it is important to discuss sufficiently what the priority objective is for the optimal management of tank cascade irrigation systems, because application of the new-type management may involve drastic changes in the existing irrigation community.

As prospective objectives, for example, improvement of the equity for water use, further expansion of irrigable area, intensification of the sustainability of the irrigation system, and so on, appear feasible. Anyway, it should be decided based on farmers' opinions with advice from an authority on irrigation. In the meantime, apart from simplistic tank water saving, the future course of long-term management for each component may be naturally clarified with the establishment of a management plan for the overall system.