Macro-Catchment Modeling and Management Studies

FINAL REPORT

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Contents

Foreword

THIS FINAL REPORT is the outcome of a study conducted in two selected catchments of Sri Lanka. The study was initiated in 1985 with financial assistance for the Major Irrigation Rehabilitation Project (MIRP). On expiry of the MIRP in mid-1993 the management of the study was taken over by the Irrigation Management Research Unit (IRMU) of the Irrigation Department.

The information generated by the study especially on the relationships between rainfall and catchment land uses; sources, transportation and deposition of sediments; improved water management practices for the command areas, etc., provide useful guidelines for better management of the catchments.

The final report submitted by Dr. Somasiri has been edited by Drs. R. Sakthivadivel and K. Azharul Haq, Senior Irrigation Specialist, IIMI and Technical Advisor, IRMU, respectively.

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The active participation of Mr. T.M.J. Bandara and Mr. Nimal Jayaratne (Soil Surveyors), Mr. Ranjith Tilekasekera (Land Evaluation Officer) and Mr. G.B.G. Samaranayake (Research Assistant) in data collection and field operations is greatly appreciated. I am very grateful to the late Mr. T.B. Samarakoon (Soil Surveyor) who gave his best in the field operations. The contribution of Mr. H.B. Nayakakorala (Research Officer) in the preparation of the final report is also appreciated very much.

The keen interest of the MIRP management in the program and its assistance in obtaining funds contributed immensely to the uninterrupted conduct of the research program. I am very grateful to Mr. U.S.N. Wickramarachchi (Project Director, MIRP) for his keen interest shown throughout the study.

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Summary

THE ERRATIC AND uncertain rainfall conditions and the variable distribution of rain both spatially and temporally were the main reasons for the inability to develop settled rainfall agriculture in the dry zone, without resorting to water conservation systems. Community-based water harvesting systems commonly referred to as "village tanks", all located within catchments of major tanks, were developed to provide supplementary irrigation for crop production in the dry zone of Sri Lanka. With population increases in the region, a conscious effort had been made to improve both major and village irrigation systems so that they would be able to irrigate more land to support the increasing population.

The water supply to many major tanks as well as to village tanks depends on their own catchments. The catchment runoff depends on many factors: the catchment characteristics, rainfall intensity and durations, water detention structures in the catchments, antecedent soil moisture content, etc. Out of these characteristics, land use is one factor that is subjected to change from season to season and that can be controlled and properly managed. The number of village tanks in a major catchment also controls the water supply to major tanks.

This study was undertaken to recommend methods to improve management of the catchments of the tank systems. The data from 35 village tanks collected over four maha seasons were analyzed. Further, the runoff plot experiments showed the extent of runoff under four important land uses. The study shows that cleared lands or *chena* lands produce high runoff (30-50% of the rainfall), whereas forest and abandoned chena with a good weed and scrub produce negligible quantities of runoff, unless the rainfall is high and continuous to produce temporary saturation of the surface soil layers. The other land uses such as village settlements, or landform units such as rock knob plains produce intermediate quantities of runoff.

Runoff from micro-catchments increased with increasing cumulative rainfall and for most micro-catchments it shows an exponential relationship. Catchment runoff starts only when rainfall is equal to or greater than about 90 mm.

Minor tanks with a catchment to full supply level capacity at the ratio of 9 ha per hectare-meter (ha.m), or less have a very low frequency of filling. If this ratio of the minor tank is 9 or less such a catchment is not effective as a source area for major tanks, where the minor tank catchment is part of a major catchment. Investigations have revealed that the density of minor tanks in the major catchments is high enough to reduce the effective catchment area of the major tanks.

Catchment runoff yields could be enhanced by suitable treatments of selected parts of micro-catchments. Increasing the runoff by soil compaction was about 60-70 percent compared to non-compacted soil. Increasing the drainage density in a catchment showed a severalfold increase in the catchment runoff, but with a slight increase in the soil erosion rate.

A relationship of runoff to rainfall or a runoff model in terms of rainfall and catchment land uses provides a suitable basis to predict runoff from a catchment; therefore, such a model would form a basis for selecting management practices. Efforts were made to develop such a relationship. Regression analysis used to develop a relationship of runoff in terms of rainfall and different land uses has not yielded a viable method.

Attempts were made to develop a simulation model. For this, each catchment was divided into small elements or cells. The runoff from an element for each rainfall event was computed based on the runoff curves developed from runoff plot data.

To predict runoff, experiments were conducted to determine the in-situ water balance. The rainfall, runoff, soil moisture storage and evapotranspiration from vegetation and crops were estimated by monitoring the soil moisture at regular intervals. Data show that forest and scrub consume nearly all the rainfall. The total water consumption by the natural vegetation has been about 1,160 mm per annum while that in the chena land has been about 900 mm per annum.

The average rate of evapotranspiration from forest and scrub was 3.2 mm/day. The moisture loss in the chena land was less and was about 2.5 mm/day. Monthly soil moisture depletion is different for the three land use types. The influence of solar radiation, soil moisture availability and the differences in the vegetation on evapotranspiration is very clear.

Natural forest and the scrub jungle have similar hydrologic properties. Both vegetation types produce low runoff compared to cleared lands or chena lands.

Soil erosion from chena lands attains critical levels. However, the soil loss from forest, scrub and abandoned chena lands is very small and is therefore not a serious problem.

Water management in the command areas of Nachchaduwa and Huruluwewa, was an additional component of this research effort which was to establish the current status of the on-farm water use and to develop improved methods of irrigation. In the first phase of the study, the technical problems, particularly on the on-farm distribution, surface water wastage, etc., were examined while the socioeconomic conditions of the water users were assessed.

In the second phase of the water management program, attempts were made to develop alternative methods of on-farm water management, particularly to develop on-farm irrigation for other field crops. Two systems of water application were tested, namely top-down and bottom-up. Further, possibilities were explored for providing on-farm supply ditches to achieve a higher water use efficiency than that obtained through the current practices.

Introduction

THIS REPORT PRESENTS the results of research work carried out on catchment management and water management in the command areas of two major irrigation schemes under the Major Irrigation Rehabilitation Project (MIRP). The important outputs of the study are given. The necessary future studies are briefly described.

Experiences from the Village Irrigation Rehabilitation Project (VIRP) and the Anuradhapura Dry-Zone Agricultural Project (ADZAP) indicated the need to assess the conditions affecting the hydrology of major tank catchments and propose suitable management practices to ensure stable water supplies to these major tanks.

Studies on water balance carried out during the implementation of the VIRP showed that water supply to village tanks was below expectations. The tanks did not fill up to full supply level on a regular basis. Originally, about 600 minor tanks were to be rehabilitated under the ADZAP. However, out of 153 tanks rehabilitated at the beginning, a large number had very low irrigation potential. Most of these tanks did not get adequate runoff from their catchments. The committee comprising the Land Use Planner, the Chief Irrigation Engineer and the Project Consultant that was set up to review the tank selection procedure for rehabilitation, concluded that rehabilitation of village tanks in major catchments would interfere with the water supply of major tanks. It was found that water resources in catchments of major tanks in the dry zone have been extensively developed. There were too many village tanks in major catchments, which reduced the effective catchment area far below the original estimates. The water supplies to major tanks are adversely affected by village tanks when developed in an ad hoc manner. This study became necessary to quantify the above noted empirical observations and recommend suitable management practices.

The present study was undertaken as a research component of the larger project, Government of Sri Lanka/World Bank (GOSL/WB) Project on rehabilitation of major tanks in the dry zone. The entire study was funded by the GOSL/WB, under the Major Irrigation Rehabilitation Project, implemented by the Ministry of Lands and Irrigation and Mahaweli Development.

The studies commenced in 1985 consisted of three parts; part 1 essentially deals with the catchment water balance, rainfall-runoff relationship, etc., while part II is on on-farm water management aspects. Part III of the study is a review of land-related legislation to assess the adequacy of the existing laws to control the use of catchment lands.

In the recent past, it has been realized that to get the maximum benefit of the tank system in the dry zone, improved water management practices are essential. Moreover, it became evident that proper water management involves not only the effective utilization of water after it is released from the tank (reservoir), but also the management of the source of water itself. Thus water management must start from the point of the incidence of rainfall in the source area.

It is necessary to define catchment management practices that would ensure a stable catchment runoff yield. The catchments of the major tanks in the dry zone are in multiple uses. The catchment lands are allocated to various uses on an ad hoc basis. The hydrologic impact of such allocations and management practices adopted under different uses are not well established. The quantitative information on land use, management practices and hydrology is lacking; therefore, it became necessary to undertake a study on catchment management so that suitable catchment management practices could be developed and adopted.

BACKGROUND

In the dry zone of Sri Lanka, the rainfall is erratic, unreliable and seasonal. Poor rainfall distribution and the lack of other water resources had been the main constraint for the agricultural development in the area. The early settlers of the dry zone developed systems of rainfall harvesting and water conservation, commonly known as the "tank systems" which served as sources of irrigation water. The supply of irrigation water was essential to stabilize the production of rice, the staple food crop in the country. The practice of irrigated rice cultivation has continued to date and it would remain as a major component of the peasant agriculture in the future.

There are several systems of irrigation and they are classified, quite arbitrarily, as major irrigation and minor or village irrigation, usually on the basis of the size of the command area. In the dry zone, major irrigation systems can be either trans-basin diversions or large reservoirs created by building dams across the valley of a large river or *oya*, which are referred to as major tanks. The minor tanks are small-scale reservoirs created by building an earth bund across a minor valley in a micro-catchment. It is very common to have a large number of these minor tanks in cascades within the catchment of a major tank.

These small tanks usually deprive the water supply to the major tanks, while they also trap a very large volume of sediment, which would otherwise silt up the major tank and reduce the live storage.

At present, there are nearly 8,000 minor tanks in operation (Ratnatunge 1979). There may be more than 7,000 abandoned tanks, some of which may be redeveloped in the future. There are about 102,000 ha of rice lands irrigated by the minor tanks, which also happen to be in the catchments of major tanks. This extent of rice lands is nearly 15 percent of the total area developed for rice cultivation in the island. Both major and minor tanks depend on the catchment yield and the direct rainfall on the tank, except those systems, where the water supply is augmented through trans-basin diversions. The tanks dependent on the catchment runoff, particularly the minor tanks, derive 65 percent of the inflow in the maha season from the catchment yield. The balance is from direct rainfall on the tank water spread. In the yala season, the reverse is true; not more than 33 percent of the yala season's inflow is from catchment runoff, while the balance is derived from direct rainfall on the tank (Somasiri 1979).

In the dry zone, none of the major catchments or micro-catchments is entirely under natural vegetation. They are highly disturbed. Any micro-catchment consists of several land uses and is subjected to different management practices. Due to "slash and burn" agricultural practices and unplanned settlements, etc., the land use composition is not stable; it is subjected to changes in the short-term as well as in the long-term.

Catchment runoff is largely influenced by factors such as rainfall amounts, intensity and duration, topography, soil properties and land uses. Unlike other factors, some of which are beyond the control of man, land use is almost completely under the control of the users. Therefore, land use is subjected to many changes arising from the agricultural and other development activities. These changes usually affect the tank water supply. Quantifying catchment runoff generated under different land uses, and the evaluation of the integrated effect of all the land uses in a micro-catchment will provide the basis for planned land use in the tank catchments. It is important to allocate lands for different uses so as to expect an appropriate runoff quantity with a certain degree of stability, to reduce extreme fluctuations and to mitigate erosion in the catchment and siltation of the tank beds.

In the extent of primary and secondary forests and scrub and cleared lands (chena) of the dry zone, the most dominant land uses are subjected to changes when farmers shift from one tank micro-catchment to another for traditional slash-and-burn cultivation. With the change in extent of cleared land

area, there is a corresponding change in the area of the forest, or scrub or both. Similarly, development of human settlements may also change the area of the scrub or forest. Such changes will influence the catchment runoff generated; therefore, the use and management of catchment lands become a key factor that determines the sustenance and the utilization potential of the tank system.

To evaluate the influence of catchment land use and management on the volume of surface runoff, the development of a runoff model is probably the most suitable step. Analysis of the sensitivity of the model with reference to the changes in the catchment will provide the basis for appropriate allocation of lands for various uses under specific management practices. A simple model will have much practical value to the planners in their efforts to decide on tank sites, capacities, renovation priorities and appropriate catchment management.

Classical runoff models proposed by Crawford and Linsely in 1966 which are deterministic in nature such as the Standford model (Fleming 1979), have been developed to accurately determine runoff. However, such deterministic models require precise measurements of a large number of parameters and variables such as rainfall intensities, infiltration capacities, slope lengths, slope classes and catchment water volume parameters. Unfortunately, in our situation, the data available are the daily or monthly totals of rainfall. The rainfall intensities are not easily measured in remote village areas of the dry zone. It cannot also be envisaged that rainfall intensity measurements would be available in the near future for most of the micro-catchments in the dry zone. Therefore, in this study, the focus was to develop a runoff model in terms of daily total rainfall, seasonal totals, catchment land uses and other easily evaluated parameters. Further, attempts are made to assess the impact of different land uses, which are subjected to annual changes.

A simple linear model for runoff from a micro-catchment will be of little use, because such a model will not reflect the impact of changes in multiple land uses encountered in the catchments. There is little practical value in estimates of runoff coefficients of different land uses. To find a solution to the problem in hand, the most suitable approach is distributed watershed modeling of surface runoff. Such a model is applicable on a point basis (Morrison, Cerling and Larsen 1990). Nevertheless, more than one single approach may prove useful in the analysis of the data in the present study.

OBJECTIVES

General Objectives

The general objectives of the studies are to:

1. Make recommendations on allocation of lands for different uses and land management practices in tank catchments in order to ensure adequate runoff to major tanks.

2. Make recommendations on water management practices in the command areas.

3. Assess the adequacy of legal provisions to enforce catchment management practices.

Specific Objectives

The specific objectives of the study are to:

1. Study the spatial variation and the distribution of rainfall in selected major catchments.
2. Estimate seasonal (maha) rainfall in sub-catchments and prepare isohyet maps for the Nachchaduwa and Huruluwewa catchments.
3. Compare runoff and soil loss under selected land uses.
4. Estimate in-situ water balance; estimate consumptive use of rainfall by different vegetation types and assess the surface and subsurface flow.
5. Develop rainfall runoff relationships for some important land uses.
6. Develop a rainfall runoff relationship for micro-catchments and major catchments in the dry zone, in terms of rainfall, land uses and other physical features of the catchments.
7. Select suitable land treatments that would enhance surface runoff without causing environmental damage.
8. Review land-related legislation to determine the adequacy of the law to implement catchment management.
9. Recommend suitable irrigation practices.

STUDY AREA

The study areas are the catchments of Nachchaduwa and Huruluwewa major tanks and the command areas of the same irrigation systems.

These catchments which are in the dry zone area have slight differences in terms of land use, rainfall and landform. The soils are similar, but with minor differences in their distribution. The soils in the two catchments may differ at soil series level; however, such differences may not affect the studies very much.

Some catchment characteristics and the climatic environment of the study area are described in the following sections.

Catchment Characteristics

The landscape of the catchment areas under study consists of level to gently undulating valleys and undulating uplands. The upland slopes rarely exceed 8 percent while the steeper slopes are found only in isolated hilly portions. There are rock knob plains and erosional remnants on some crest areas of the landscape; commonly they occupy the divides of micro-catchments.

The upland soils are well-drained Reddish Brown Earths (RBE), with moderate infiltration capacities. Infiltration rates are in the range of 12-25 mm per hour (hr) after four hours. The water-holding capacities are low to moderate. The total soil porosity is about 40 percent. The soils in valleys are fine-textured (clay) Low Humic Gley and various alluvial soils. The physical properties of these soils are quite different from those of the RBE soils. The infiltration rates are about 25 percent of that of the RBE soils

on adjacent uplands. The porosity and water-holding capacities are somewhat similar. The groundwater level reaches the surface in the latter part of the maha season.

Climate

Nachchaduwa and Huruluwewa catchments are in the agro-ecological region DL, of the dry zone of Sri Lanka (Agro-ecological map published by the Land and Water Use Division, Department of Agriculture 1976). The rainfall in the area is seasonal and its annual average is about 1,500 mm. The temperature is high and uniform throughout the year and is in the range 30-34 °C. The relative humidity values are high being in the range of 77-91 percent. The average wind velocity is 3.1 km/hr, but the wind speeds are high during the summer months; these winds are dry and desiccative. However, the wind velocities drop sharply in the evenings.

Rainfall

The monthly rainfall follows a bimodal pattern of distribution with the main maha rainy season, from October to January and the minor yala rainfall season, from mid-March to mid-May. Nearly 75 percent of the annual total rainfall occurs in the maha season, a period not longer than three and a half months. The maha rains commence in October with convectional high intensity afternoon or evening thunderstorms. These rains are immediately followed by the northeast monsoon rains in the latter part of November and the maha rains usually end in mid-January. The maha season rains are followed by a short dry period from February to March. The yala rains commence in the latter half of March and end in the early half of May. They are convectional rains. These rains are followed by a protracted dry period with dry winds and this long dry period ends with the onset of maha rains in late September or October.

Evaporation

The annual evaporation from a free water surface is more than the annual average rainfall. The evaporation from a free water surface is high during the summer months, but moderate during the rainy season. The evaporation rate in the maha rainy season (October to January) is about 3.5 mm/day and that in the yala season (March to August) is about 5-6 mm/day. The total precipitation is in excess of evaporation only in the months of October, November and December. The other months can be classified as water-deficit months.

Part I

Methods of Study

NACHCHADUWA AND HURULUWEWA catchments were subdivided into sub-catchments or micro-catchments several of which were selected to represent the different catchment conditions in different parts of the major catchment. In each selected micro-catchment, a single minor tank or a cascade of two or three minor tanks was selected for a detailed study of the tank water balance.

For each selected tank, the components of the tank water balance model were estimated. The land areas allocated to each kind of land use were estimated from aerial photo-interpretation and field checking.

Standard runoff plots were established to assess the rainfall runoff relationship for each kind of important land use.

Tank bed surveys were carried out to develop the relationship between the tank capacity and the water level.

TANK WATER BALANCE

The change in storage of any given tank for a given time interval (daily, weekly, seasonally) is the difference between the total inflow to the tank and the total outflow from the tank.

ΔS = Change in storage
ΔS = Inflow - outflow
$\Delta S = (R_o + R_f) - (I + E + S + P + O)$

where,

R_o = Rainfall
R_f = Catchment runoff
I = Irrigation issues
E = Evaporation from tank surface
S = Seepage, bund leakages, etc.
P = Deep percolation
O = Overflow over the spillway.

The above components are measured either individually or as combined factors. Particularly, the evaporation losses, seepage and leakage losses and the deep percolation had to be estimated as combined losses. (All units of measurement are in millimeters.)

DIRECT MEASUREMENTS

Agro-meteorological stations were established in each major catchment. Additional rain gauging stations were established with the installation of non-recording rain gauges in each micro-catchment (figure 1). Complete weather records are kept for each agro-meteorological station, so that water balance models could be developed later on. *Rainfall, evaporation, irrigation issues, tank storage, and land use and land use changes were measured directly.*

Rainfall

Daily rainfall in the tank area was measured with a non-recording rain gauge to an accuracy of ± 0.25 mm.

As the area of the micro-catchments were about one square mile (2.5 sq. km) no attempt was made to install several rain gauges in the same catchment area.

Evaporation

Evaporation from a free water surface was measured with a class A pan at two sites in the Nachchaduwa Catchment and one site in the Huruluwewa Catchment.

Irrigation Issues

Issues from the tank for irrigation were measured with flumes by recording the height of flow at regular intervals during irrigation. Before the installation of the flume but during the irrigation, the issues were estimated from the changes in the elevation of the water level in the tank.

Tank Storage

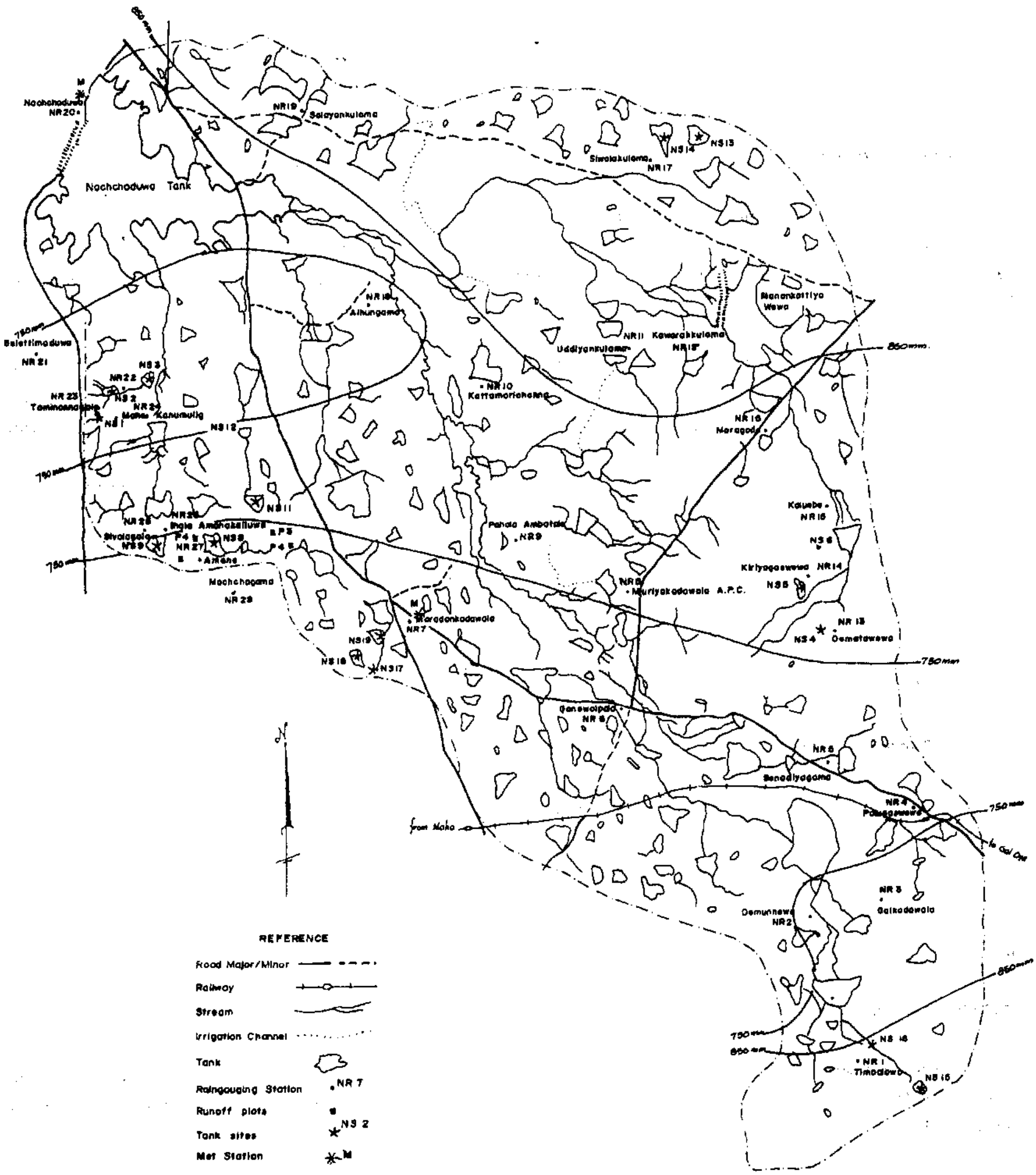
Tank storage at any given time is determined from the elevation of the water surface, by making use of the elevation capacity relationship.

From the tank bed survey and the volume calculated between two consecutive contours the relationship of elevation to capacity was determined. These curves provide the volume of the tank at any elevation.

Land Use and Land Use Changes

The areas under major land uses in the micro-catchments in Nachchaduwa and Huruluwewa were estimated using the most recent aerial photographs and field surveys. In the micro-catchments studied, the main land uses subjected to change are the chena lands and different forest types: primary forest,

Figure 1. Map of Nachchaduwa Catchment.



secondary forest, scrub and recently abandoned chena. These land use categories are easily identified on aerial photographs. The most accurate information on the changes in land uses could be easily obtained if aerial photographs are taken at regular intervals, but this is not done because of the costs involved. The next best approach was to undertake the survey of each catchment and update the information.

INDIRECT MEASUREMENTS

Tank Water Losses

Deep percolation, evaporation and bund seepage and leakage from the minor tanks could not be measured directly. The rate of water loss from minor tanks depends on the surface area of water in the tank, which is a variable. Therefore, the rate of total water loss for different surface areas corresponding to different water levels is estimated by the change in the volume of water in the tank when there are no inflows and irrigation issues.

The evaporation, deep percolation and bund leakage are difficult to measure separately. The overflow is only an occasional event. However, to measure the overflow, a controlled cross-section was made at the spillway. Values of evaporation from the tank surface, percolation and bund leakage were obtained from the estimate of the total losses per day, during short dry spells, ranging from 3 to 7 days, at which time both inflow and irrigation were not taking place. Relationships between tank water level and water loss were developed using these data.

Field Experiments

The following field studies were carried out to determine the influence of different land uses on rainfall-runoff and soil loss, to complete the in-situ water balance and to enhance catchment yields.

1. Runoff plot experiments.
2. In-situ water balance studies under different land uses.
3. Different land treatments for runoff generation.
4. Measurement of runoff in micro-catchments and the development of a runoff model.

RESULTS

Rainfall in Maha

The present observations and earlier studies (Somasiri 1979) show that the main contribution to tank storage is from catchment runoff during maha. The contribution of runoff to the storage in yala is not very significant. The distribution of monthly average rainfall for different locations in the two catchments are shown in histograms (figures 2 to 8).

The rainfall in maha commences in late September. Figures 2 to 8 indicate that a major portion of the rains fall in October and November. In some years, December rainfall is considerably high. Daily data show that in each month there are days with very heavy rainfall. The year-to-year variation of monthly rainfall is very high (tables 1 to 5). Also there is a considerable variation in the seasonal totals.

In maha the rainfall is far in excess of the evaporative demand of the same period. Therefore, a considerable portion of the rainfall is stored in the soil profile while producing a substantial quantity of runoff.

There is a considerable spatial variation of rainfall in the two catchments studied. The seasonal average rainfall varies from about 650 mm in the upper part of the catchments in the south to above 900 mm in the lower part of the catchments in the north. Rainfall decreases in the northeast, southwest direction. The isohyets for the catchments are given in the map.

Tables 1 to 5 show that the place-to-place variation in the monthly rainfall is very high. The seasonal rainfall also varies from place to place as well as from season to season. In Kalumbe micro-catchment on the northeast of Ritigala Range, the rainfall is consistently high. On the other hand, rainfall is lowest in micro-catchments on the southwest and west of Ritigala. This pattern of variation distinctly affects the runoff process; therefore, the catchment yield varies from micro-catchment to micro-catchment. It is also possible to identify the micro-catchments that contribute more to the storage in the major tanks, Nachchaduwa and Huruluwewa.

Runoff Plot Experiments

In Nachchaduwa and Huruluwewa catchments runoff and soil loss were measured for four major land use types: forest, scrub, chena (lands under shifting cultivation) and teak plantations. One representative site for each land use was selected for the study. Runoff plots of 22.1 m length and 7.31 m width with a divided collecting tank system were constructed in each site with three replications. Daily runoff was estimated by measuring the volume of water collected in the tank. The soil loss was estimated by drawing representative samples from the soil-water suspension in the tanks.

Measurements show that runoff generated from plots vary with the land use. Of the total maha rainfall, runoff under chena is in the range of 20-35 percent; under forest and scrub it is about 2 percent and under teak plantations it is in the range 10 - 15 percent. Runoff under chena showed a linear relationship with rainfall, but under other land uses such a relationship is not apparent. The contributions to catchment yield from forest and scrub jungle lands appear to be very similar. Thus forest lands and scrub or abandoned chena lands have very similar hydrologic properties. These lands would probably generate runoff only under very high rainfall conditions and after much rain to saturate the profiles. Major contributions to catchment yield in the dry zone catchments are from chena (cleared) lands and areas covered with surfaces such as settlements, and built up areas or housing sites and rock knob plains.

Figure 2. Monthly average rainfall (Halmillawa).

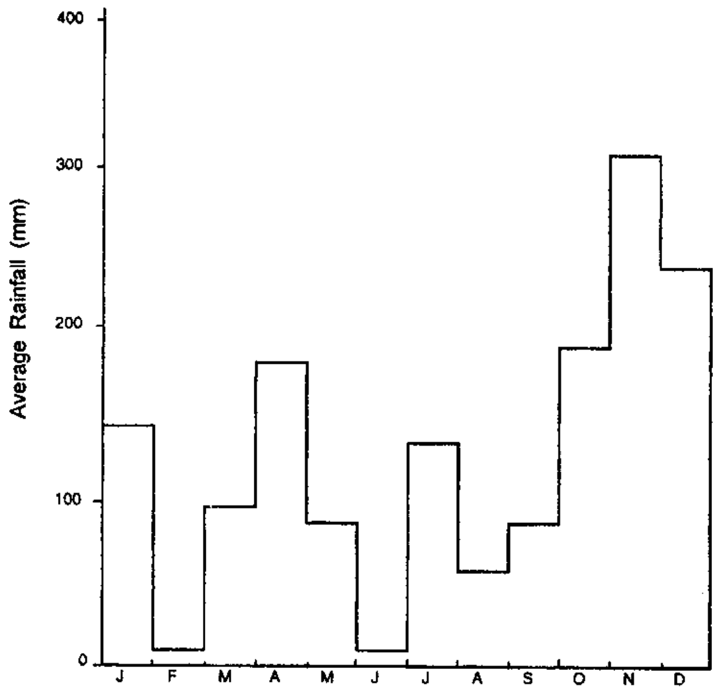


Figure 3. Monthly average rainfall (Polattawa).

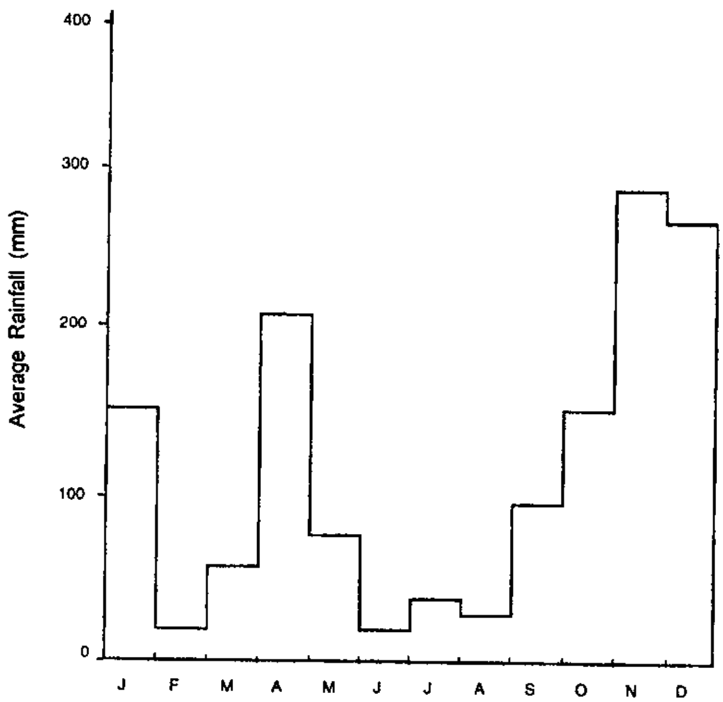


Figure 4. Monthly average rainfall (Maradankadawala).

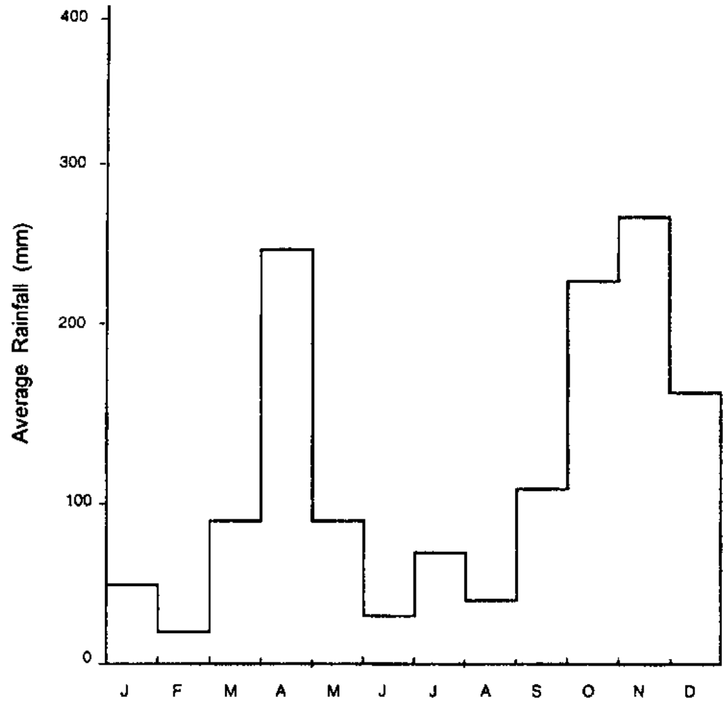


Figure 5. Monthly average rainfall (Senadiriyagama).

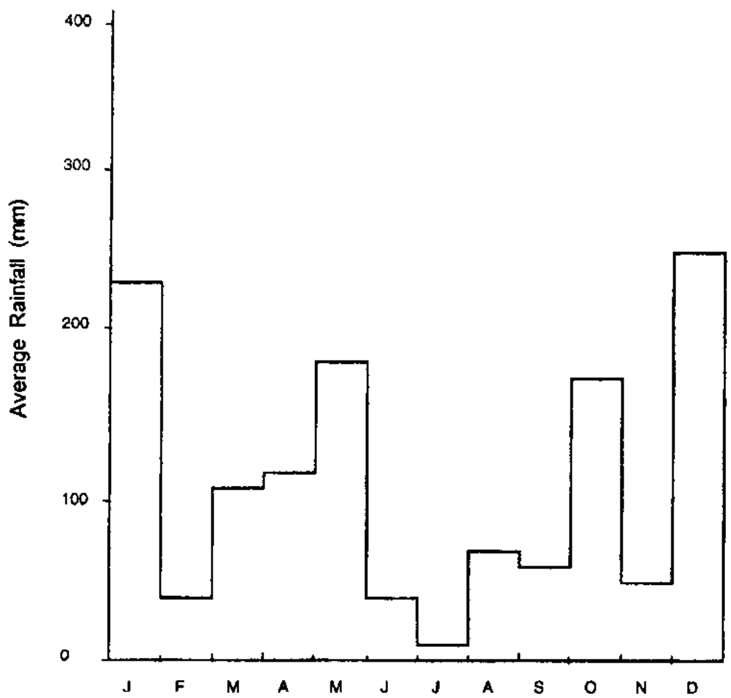


Figure 6. Monthly average rainfall (Mahakanumulla).

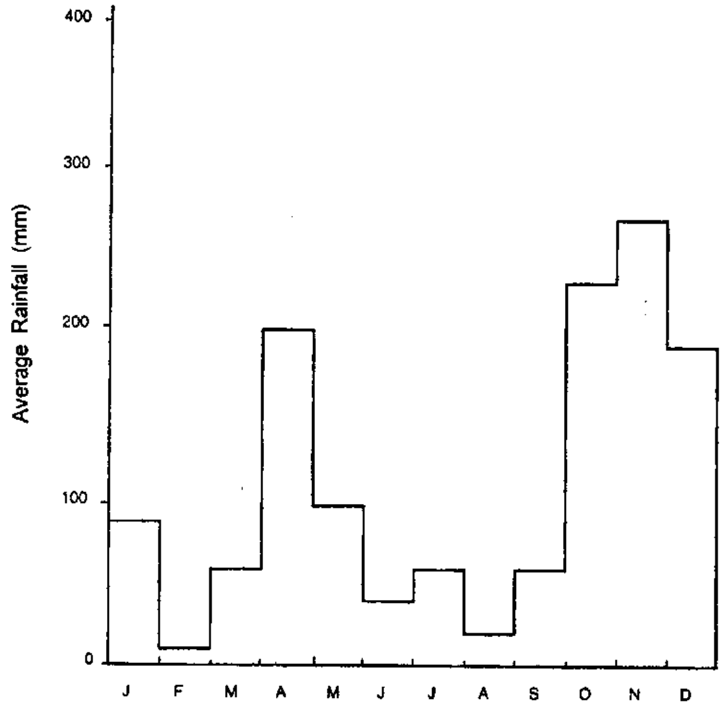


Figure 7. Monthly average rainfall (Pahala Ambatale).

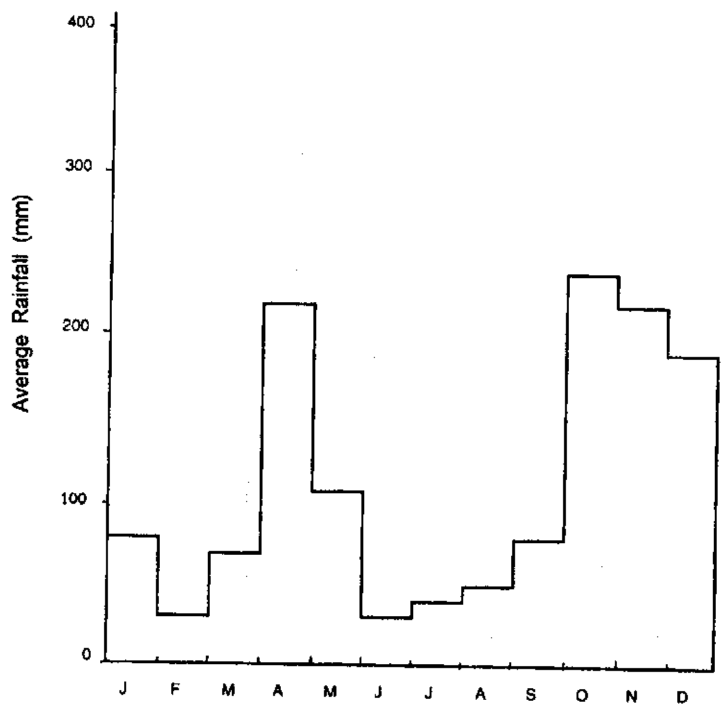


Figure 8. Monthly average rainfall (Timbalawa).

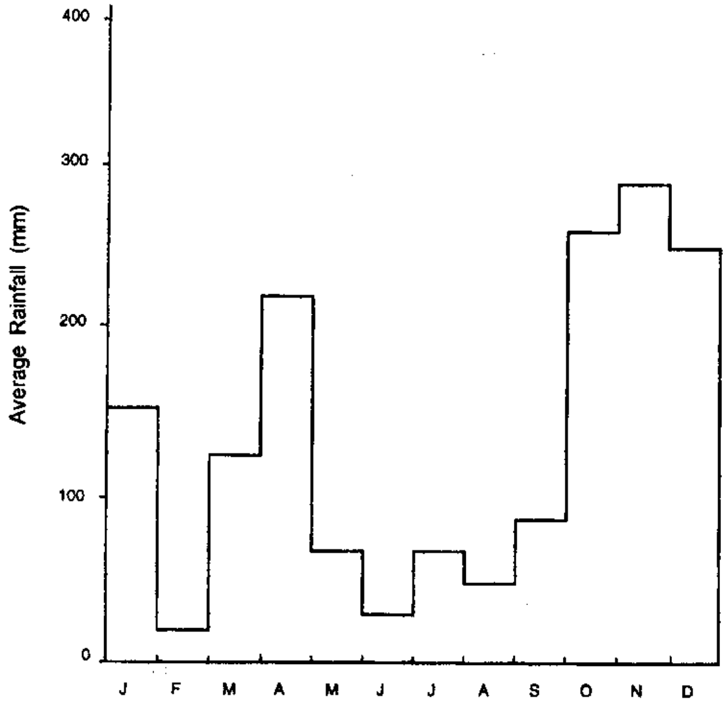


Table 1. Monthly total rainfall (mm), maha, 1987.

Tank	Legend no.	Sept.	Oct.	Nov.	Dec.	Jan.	Total
Thimbawa	NR 1	107.9	438.2	162.9	74.8	30.1	813.9
Demunnawa	NR 2	62.4	352.4	194.4	42.3	20.1	671.6
Galkadawala	NR 3	60.7	128.4	222.7	61.3	35.9	509.0
Palugaswewa	NR 4	36.1	367.9	226.3	64.0	0	694.3
Maradankadawela	NR 7	76.5	422.4	128.0	82.4	19.4	728.69
Pahala Ambatale	NR 9	93.7	363.5	174.7	66.7	33.0	731.6
Kattamurichchan	NR 10	123.8	413.4	159.5	89.2	17.3	803.2
Uddiyankulam	NR 11	160.8	467.0	238.9	56.7	0	923.4
Kawarakkulama	NR 12	150.0	544.2	177.8	66.1	0	938.1
Dematawewa	NR 13	94.4	384.8	208.2	145.9	32.0	865.3
Keeriagaswewa	NR 14	195.2	422.2	161.5	114.5	25.4	918.8
Kalumbe	NR 15	134.7	408.7	199.2	104.7	24.0	1087.3
Moragoda	NR 16	75.97	453.5	141.8	141.5	18.0	830.8
Wagayakulama	NR 22	174.3	362.8	112.9	139.8	26.8	816.6
Thamanagala	NR 23	15.1	370.7	131.5	108.8	25.5	651.6
Mahakanumulla	NR 2	73.3	394.0	128.3	158	0	753.9
Sivagala	NR 25	224.8	221.3	133.0	132.0	0.8	711.9
I.Amnakattuwa	NR 26	216.9	250.6	131.3	129.7	0.9	729.4
Amane	NR 27	183.7	424.1	142.0	126.7	10.1	886.6
Machchagama	NR 28	205.5	312.9	176.5	103.5	10.0	808.4

Table 2. Monthly total rainfall (mm), maha, 1988.

Tank	Legend no.	Sept.	Oct.	Nov.	Dec.	Jan.	Total
Thimbalawa	NR 1	*		83.3	233.3	168.5	85.8
Maradankadawala	NR 7	80.5	37.4	157.8	161.2	72.7	509.6
Pahala Ambatale	NR 9	45.3	15.5	229.9	148.6	100.5	539.8
Katta-murichchan	NR 10	75.0	21.2	229.1	77.6	100.0	502.9
Uddiyankulam	NR 11	40.1	82.9	204.0	121.3	*	
Kawarakkulama	NR 12	27.0	*		195.8	109.4	*
Dematawewa	NR 13	82.7	54.5	310.9	194.6	111.9	754.6
Keeriagaswewa	NR 14	131.2	82.4	288.9	154.4	145.6	802.5
Kalumbe	NR 15	73.5	127.0	265.2	138.7	159.8	764.2
Moragoda	NR 16	38.9	182.4	133.3	158.3	157.0	669.9
Athungama	NR 18	63.2	45.5	12.8	34.3	*	
Solayankulama	NR 19	0.1	78.05	98.09	*		*
Selesthimaduwa	NR 21	61.9	34.2	31.1	42.4	69.6	239.2
Wagayakulama	NR 22	73.8	80.4	156.1	52.7	44.2	407.2
Thamanagala	NR 23	72.6	82.8	143.6	51.6	*	
Mahakanumulla	NR 24	30.8	49.2	251.4	59.2	59.0	449.6
Sivagala	NR 25	64.3	78.0	235.4	64.0	59.9	501.6
I. Amanakattuwa	NR 26	64.2	76.0	225.1	70.5	58.7	494.5
Amane	NR 27	69.2	48.1	248.2	80.3	*	
Machchagama	NR 28	48.0	63.5	111.8	67.2	*	

Table 3. Monthly total rainfall (mm), maha, 1989.

Tank	Legend no.	Sept.	Oct.	Nov.	Dec.	Jan.	Total
Thimbalawa	NR 1	18.5	296.5	223.8	87.6	215.6	842.0
Demunnaw	NR 2	-	-	-	-	-	-
Galkadawala	NR 3	20.2	227.7	222.1	63.0	300.9	833.9
Palugaswewa	NR 4	-	-	-	-	-	-
Maradankadawala	NR 7	62.5	252.2	402.3	50.6	205.8	1053.7
Pahala Ambatale	NR 9	-	-	-	-	-	-
Kattamurichchan	NR 10	-		277.9	78.1	204.6	560.6
Uddiyankulam	NR 11	-	-	-	-	-	-
Kawarakkulama	NR 12	61.0	114.3	269.6	-	-	444.9
Dematawewa	NR 13	29.5	183.2	296.8	41.4	104.6	655.5
Keeriagaswewa	NR 14	35.0	275.7	434.0	58.5	181.6	984.7
Kalumbe	NR 15	51.1	203.3	314.6	81.9	185.4	736.3
Moragoda	NR 16	112.2	10.5	351.5	72.0	202.0	748.2
Wagayakulama	NR 22	58.9	246.9	295.5	-	-	601.3
Thamanagala	NR 23	-	-	-	-	-	-
Mahakanumulla	NR 24	0.0	206.6	322.1	29.5	214.5	772.7
Sivalagala	NR 25	16.2	286.6	317.2	33.5	198.2	851.9
I. Amanakattuwa	NR 26	16.4	399.7	246.0	20.2	173.6	855.9
Amane	NR 27	11.2	37.4	213.3	29.5	181.7	473.1
Machchagama	NR 28	-	-	-	-	-	-

Table 4. *Monthly total rainfall (mm), maha, 1990.*

Tank	Legend no.	Sept.	Oct.	Nov.	Dec.	Jan.	Total
Thimbalawa	NR 1	31.4	244.4	141.4	230.6	205.6	863.4
Demunnawa	NR 2	60.1	293.6	81.4	176.3	214.4	825.8
Galkadawala	NR 3	21.4	242.0	115.9	251.9	266.2	897.4
Palugaswewa	NR 4	-	-	-	-	-	-
Maradankadawala	NR 7	145.4	404.5	105.2	249.6	170.5	1075.2
Pahala Ambatale	NR 9	84.5	286.7	101.6	225.0	219.2	917.0
Kattamurichchan	NR 10	134.2	329.9	137.0	157.5	153.4	912.6
Uddiyankulam	NR 11	-	-	-	-	-	-
Kawarakkulam	NR 12	102.3	264.7	115.8	214.1	241.5	938.4
Dematawewa	NR 13	19.5	181.5	75.1	205.2	201.7	683.0
Keeriagaswewa	NR 14	21.1	186.3	82.0	250.1	218.4	757.9
Kalumbe	NR 15	17.7	203.1	198.8	81.6	138.9	640.1
Moragoda	NR 16	0.0	261.7	99.8	163.0	206.2	730.7
Wagayakulama	NR 22						
Thamanagala	NR 23	-					
Mahakanumulla	NR 24	50.6	355.2	141.0	144.8	142.7	834.3
Sivalagala	NR 25	52.6	349.3	147.1	152.7	105.8	807.5
I. Amanakattuwa	NR 26	77.1	304.8	148.8	159.4	123.0	813.1
Amane	NR 27	-	-	-	-	-	-
Machchagama	NR 28	-	-	-	-	-	-

Table 5. *Monthly total rainfall (mm), maha, 1991.*

Tank	Legend no.	Sept.	Oct.	Nov.	Dec.	Jan.	Total
Thimbalawa	NR 1						
Demunnawa	NR 2						
Galkadawala	NR 3						
Palugaswewa	NR 4						
Maradankadawala	NR 7	57.9	259.2	209.8	327.0	9.5	863.4
Pahala Ambatale	NR 9	0.0	288.2	178.8	391.3	0.0	858.3
Kattamurichchan	NR 10	10.0	272.6	205.5	339.1	25.6	852.8
Uddiyankulam	NR 11	-	-	-	-	-	-
Kawarakkulam	NR 12	0.0	253.6	210.8	362.7		827.1
Dematawewa	NR 13						
Keeriagaswewa	NR 14	1.5	170.3	179.9	241.3	63.0	656.0
Kalumbe	NR 15						
Moragoda	NR 16						
Wagayakulam	NR 22						
Thamanagala	NR 23	-	-	-	-	-	
Mahakanumulla	NR 24	0.0	143.0	176.3	406.9	24.2	750.4
Sivalagala	NR 25	1.0	235.6	235.6	432.4	17.7	922.3
I. Amanakattuwa	NR 26	0.8	252.1	236.5	278.7	18.7	786.8
Amane	NR 27	-	-	-	-	-	
Machchagama	NR 28	-	-	-	-	-	-

Soil Loss

When lands are cleared of vegetation for arable cultivation an inevitable problem would be soil erosion and siltation of water ways and the storage system. Hence, soil loss studies were also carried out in the same runoff plots.

As in runoff, soil loss was also higher on chena than on scrub and forest (table 6). The soil loss on chena exceeded the allowable limit of 9,000 kg/ha/year by 17 percent in 1988. However, the soil loss in 1989 was only about 1/3 of the limit. The variations can be well explained by the differences in rainfall between years (table 6). The results are in agreement with the well-established fact that soil loss is negligible from land surfaces well covered with vegetation.

Table 6. Rainfall, runoff and soil loss under three different land uses in the Nachchaduwa Catchment.

Parameters	Cleared land		Scrub		Forest	
1987/88	maha	yala	maha	yala	maha	yala
Rainfall (mm)	802	382	558	275	727	413
Runoff (mm)	292	73	7	4	8	0
Soil loss (kg/ha)	10334	215	88	20	66	0
Runoff %	36.4	19.1	1.3	1.5	1.1	0
1988/89						
Rainfall (mm)	342	165	587	338	323	243
Runoff (mm)	188	27	2	1	3	0.3
Soil loss (kg/ha)	3273	484	78	4	21	1
Runoff %	54.9	16.4	0.5	0.3	0.7	0.1

The soil loss rates, expressed in kg/mm of rainfall, decrease with time from the onset of maha rains to the end of the season. The peak soil loss rates coincide with the initial inter-monsoonal rains. The decrease in the rate of soil loss with time as the season progresses is not dependent on the rainfall. There may be a range of other factors responsible for this phenomenon. However, surface conditions and vegetative cover can be considered the main factors responsible for this decrease.

At the beginning of the season, when the inter-monsoonal rains occur the fields with loose and bare surfaces are ready for planting. With time, surface soils get compacted and a canopy develops making the soil less vulnerable to erosion even if the runoff increases. Our results are consistent with those of Pathak, Miranda and El-Swaify (1983) for Alfisols in India.

Soil loss on chena was also highly variable and sometimes exceeded the allowable limit (9,000 kg/ha/yr). Losses from scrub and forest lands were less than 1.5 percent of the limit. Soil loss from teak plantations was observed to vary within the range of 3,000 - 6,000 kg/ha/yr and during most of the years it was about 50 percent of the allowable limit.

Land Use in Micro-Catchments

In the two major catchments, the lands are put to several uses, which can be expected to have different runoff coefficients, and therefore influence catchment yield. The main components of the land use in the

micro-catchments are primary forest, secondary forest, scrub land, abandoned chena, chena, homestead, rice lands, rock knob plain, erosional remnant, village tank and teak plantations. From a separate study conducted to compare the influence of several of these land uses on rainfall runoff, it is concluded that the primary forest, secondary forest and scrub, and abandoned chena with profuse weed growth behave very similarly. Therefore, all these different uses have been treated as a single use.

Tables 7, 8 and 9 show that the extent under some land uses is more or less fixed. For example, land use in the rock knob plain, erosional remnants and tank area are constant (tables 7 and 8). However, the land uses on which there is direct interference of man vary from season to season and from micro-catchment to micro-catchment. The comparison of land uses in the same micro-catchment in different seasons shows that the chena area is subjected to drastic changes. It is also evident that some micro-catchments have very low chena compared to other micro-catchments. The component also appears to change somewhat. In this case, even though the changes are small, they may cause a greater change in the runoff of rainfall. The rice area reduces the runoff due to land formation facilitating ponding of water. However, in a major storm it influences runoff positively by bund overtopping and breaching which would normally produce more runoff.

The land use studies in micro-catchments and the plot experiment results reported herein indicate that land use is a major component that influences the catchment yield. Further, it is necessary to allocate definite land areas for the different uses to manage the catchments for adequate seasonal yield and to mitigate irrigation tank siltation.

Still further, in catchments where water yield is inherently low due to catchment conditions, certain areas can be treated to generate runoff as a catchment management practice, while in some other areas it may be necessary to improve the conservation of the rainfall at the point where it falls. For example, stabilization of chena farming or application of conservation farming techniques or rainfall harvesting in the croplands may be necessary in the future, which must be compensated for by creating conditions elsewhere in catchments to produce more yield under controlled conditions.

A map showing the tanks selected for the study with their nomenclature is essential for understanding the tank catchment behavior.

Table 7. The distribution of land use (ha) in some selected village tank micro-catchments within the Nachchaduwa Major catchment, maha, 1987/88.

	Land use types (extent in ha)							
Tank no.	Chena	Forest and abandoned	Home garden	Rice	RKP	ER	Tank	Teak area
NS_2	47.8	40.58	2.26	18.1	1.47	1.04	15.10	-
NS_7		54.95	-	-	2.2	-	7.34	0.52
NS_8	3.88	56.27	0.81	7.26	-	-	18.79	38.37
NS_9	16.01	117.63	5.69	12.71	-	-	15.6	
NS_{10}	34.11	19.74	1.79	14.56	-	-	15.77	
HS_3	19.22	120.79	7.95	3.47	-	-	9.16	
HS_4	27.22	10.42	138.18	173.54	1.15	1.39	20.72	
HS_8	137.97	149.15	12.32	2	0	0.27	0	24.94
HS_9	81.71	274.53	9.62	1.91		0	0	15.48

Note: In this table and some subsequent ones, RKP = rock knob plain, and ER = erosional remnants; area indicated includes the area of the study tank and other tanks in the micro-catchment.

Table 8. The distribution of land use (ha) in some selected village tank micro-catchments within the Nachchaduwa Major catchment, maha, 1988/89.

Tank no.	Land use types (extent in ha)							
	Chena	Forest and chena	Home garden	Rice	RKP	ER	Tank area	Teak
NS_2	16.34	74.72	6.33	11.37	1.47	1.04	15.1	-
NS_7	-	54.95	-	-	2.2	-	7.34	0.52
NS_8	3.88	96.27	0.81	7.26	-	-	18.79	38.37
NS_9	16.01	118.06	5.69	12.71	-	-	15.6	-
NS_{11}	1.37	47.52	0.28	-	-	-	9.83	-
NS_{12}	26.55	248.82	12.76	47.08	14.96	46.45	44.88	-
NS_{14}	60.78	48.61	4.12	38.04	0.16	0.09	35.07	-
NS_{16}	19.51	153.51	37.00	45.92	1.65	-	25.62	237.29
HS_6	51.05	182.16	0.39	0	45.95	2.47	42.36	-
HS_4	15.71	194.2	139.45	21.52	1.15	1.39	20.72	-
HS_7	12.01	335.97	41.05	44.54	11.20	1.60	31.41	-
HS_8	30.64	240.91	27.83	0	0.27	0	24.95	-
HS_9	38.88	316.56	1.91	0	0	0	15.48	-
HS_{14}	249.72	84.78	0	33.18	14.37	0	69.82	-

Table 9. The distribution of land use (ha) in some selected village tank micro-catchments within the Nachchaduwa and Huruluwewa Major catchments, maha, 1989/90.

Tank no.	Land use types (extent in ha)							
	Chena	Forest and abandoned chena	Home garden	Rice	RKP	ER	Tank	Teak
NS_2	10.71	80.56	6.12	11.37	1.47	1.04	15.1	-
NS_7	1.44	53.51	-	-	2.2	-	7.34	0.52
NS_8	-	100.15	0.81	7.26	-	-	18.79	38.37
NS_9	10.77	123.26	5.73	12.71	-	-	15.6	-
NS_{10}	0.77	48.19	0.28	-	-	-	9.83	-
NS_{12}	25.62	249.75	12.76	47.08	14.96	2.64	46.45	44.88
NS_{14}	58.42	50.97	4.12	38.04	0.16	0.09	35.07	-
NS_{16}	31.65	164.53	40.76	45.23	1.65	-	25.6	241.07
HS_6	4.06	28.99	0.55	0	45.95	2.47	42.36	-
HS_4	0	208.18	141.18	21.52	1.1	1.38	20.72	-
HS_7	185.0	259.91	46.91	44.54	11.2	1.60	31.41	-
HS_9	47.66	58.51	13.74	1.91	0	0	15.48	-
HS_{13}	225.24	210.67	0	0	11.6	3.55	39.24	-
HS_1	116.99	183.42	0	33.18	14.37	0	69.82	-

IN-SITU WATER BALANCE STUDIES UNDER DIFFERENT LAND USES

Well-drained Reddish Brown Earth sites with 3-4 percent slope were selected for the study. Daily rainfall was measured by non-recording type rain gauges close to the experimental sites. Runoff plots with divided tank system were constructed to measure surface runoff. Soil moisture measurements were made at regular intervals at 30, 60, 90, 120, 150, 180, 210, 270 and 300 cm depths from the surface using a neutron moisture meter. Perforated PVC tubes were installed up to the hard rock to observe the groundwater table.

Lateral flow in and out from the soil profile at the experimental sites was considered negligible. Further, as the radius of influence of the moisture meter is limited, the volume of soil monitored is small

compared to the large body of soil in the landscape; hence, it is safe to assume the net gain in moisture in the measured volume of soil due to lateral flows as zero.

The results show that, the evapotranspiration (ET) under all land uses considered varied over a wide range during both maha and yala seasons. The ET rate was low when soil moisture was limiting, but it increased with the build-up of soil moisture levels. Under very dry conditions when soil moisture levels were very low, plants were capable of maintaining a lower rate of ET. The ET rates increased with the increases in soil moisture content in the soil profile.

The ET of natural forest cover was in the range of 0.2 - 6.0 mm/day, the lower ET values occurring when the soil moisture storage was very low and the higher ET values occurring when the soil was wet. The rate of loss of soil moisture from the profile was high immediately after wetting of the surface layers. The ET for forest-natural vegetation averaged about 3.5 mm/day in the maha season and 2.8 mm per day in the yala season (table 10). The total soil moisture loss by forest vegetation and scrub jungle varied from maha season to maha season. This variation appeared to be related to the number of days of high soil moisture content, that is, it depended on the rainy days in the maha season and also on the per day rainfall. In the season with 45 percent moisture loss in mid-January, there were lesser rainy days than in the season when moisture loss was 62 percent (tables 11 and 12).

The ET from scrub or abandoned chena was very similar to the ET pattern of the forest vegetation. The daily ET rates varied from 0.1 to 6.8 mm/day. The average ET rates of scrub vegetation varied from 3.6 mm/day in maha to 2.7 mm/day in yala (table 10). The monthly ET rates were similar for forest and scrub, but were different for chena (table 13). The variations appear to depend on the soil moisture storage, solar radiation and the vegetation type and their growth habits.

The average ET rates from chena lands in maha and yala were 2.1 mm/day and 2.8 mm/day, respectively (table 10).

At the end of maha, moisture consumption of both natural forest vegetation and scrub jungle was about 75 percent of the maha rainfall. Moisture used in chena was similar during both maha seasons (1991/92 and 1992/93) for which data are available and it was around 40 percent of the total rainfall (table 12).

At the end of each maha, the rainfall stored in the soil profile varied from year to year for the three land use types studied. The amount of moisture stored under forest and scrub depended on the rainfall distribution in the season and the moisture consumed by the vegetation. The moisture stored in the soil of chena land varied only within a very narrow range.

The moisture consumed by all three vegetation types, forest, scrub jungle and chena/fallow was similar in yala. In all three land use types total moisture loss exceeded the total rainfall received in yala. By the end of yala, nearly all the soil moisture that was stored from maha and yala rains was lost as evapotranspiration (table 14).

The annual average ET rates of forest and scrub were the same, i.e., 3.2 mm/day. The annual average of ET rate in chena/fallow was 2.5 mm/day. During the period 26.08.1992–26.08.1993 for which a complete data set is obtained, the annual total water consumption by forest and scrub was very similar and nearly all the incident rainfall was used. The annual water consumption of chena was about 72 percent of the annual rainfall.

Table 10. Seasonal and annual averages of evapotranspiration under different land uses (mm/day).

Land use	Season	Seasonal average ET (mm)	Annual average ET (mm)	Range observed (mm)
Forest	Maha	3.5	3.2	0.2 - 6.0
	Yala	2.8		
Abandoned chena	Maha	3.6	3.2	0.1 - 6.8
	Yala	2.7		
Chena/fallow	Maha	2.1	2.5	0.1 - 6.0
	Yala	2.8		

Note: ET = Evapotranspiration (mm).

Table 11. Seasonal water balance under different land uses (mm).

Land use	Season	RF	SMB	RO	DP	ET
Maha	91/92	997.2	460.3	9.8	80.7	446.6
Forest	92/93	796.8	104.8	10.1	67.3	614.5
Yala 92	-	-	-	-	-	
93	341.0	-205.7	0	0	546.6	
Maha 91/92	915.2	404.8	2.4	60.1	447.6	
92/93	856.4	148.0	0	72.2	636.5	
Ab.Chena						
Yala 92	-	-	-	-	-	
93	366.5	-156.6	0	0	523.1	
Maha 91/92	927.6	263.4	181.0	108.5	375.0	
Chena/						
Fallow	92/93	888.7	291.4	129.3	94.6	373.3
Yala 92	-	-	-	-	-	
93	382.9	-265.0	102.4	0	545.5	

Notes: RF - Rainfall.
SMB - Soil moisture balance.
RO - Runoff.
DP - Deep percolation.
ET - Evapotranspiration.
Ab. - Abandoned.

Table 12. Evapotranspiration under different land uses during maha season (mm).

Land use	Year	RF	ET			
			At mid Jan.		End of maha	
			Total	% RF	Total	% RF
Forest	91/92	997	446	45	-	-
	92/93	797	478	60	615	77
Ab.Chena	91/92	915	448	49	-	-
	92/93	856	539	62	637	74
Chena	91/92	928	375	40	-	-
	92/93	889	292	39	373	42

Note: Ab. = Abandoned.

Table 13. Monthly total evapotranspiration under different land uses (mm).

Land Use	Month											
	Ja	F	Mr	Ap	My	Je	Jl	Ag	S	O	N	D
Forest	130	158	138	95	80	53	27	29	49	101	117	109
Ab.Che.	118	91	170	117	83	49	37	26	69	119	128	125
Che/Fa.	74	77	99	78	120	125	56	20	39	46	75	81

Notes: Ab. Che - Abandoned chena.
Che/Fa. - Chena/fallow.

Table 14. Annual water balance (mm) under different land uses (period: 1992.08.26–1993.08.26).

Land use	RF	Soil moisture balance	RO	DP	ET*	Total	% of RF
Forest	1137.8	-100.9		10.1	67.3	1161.1	102
Ab.Chena	1222.9	-8.6	0	72.2	1159.6	95	
Chena/ Fallow	1269.5	26.0	231.7	94.6	916.8	72	

Notes: RF - Rainfall.
RO - Runoff.
DP - Deep percolation.
ET - Evapotranspiration.
Ab. - Abandoned.

* The moisture balances are small and some values negative; probably there is some overestimation of ET due to the method of calculations. In the long term, these soil moisture balance values could assume a zero value, which is expected.

Soil moisture storage at the end of any maha season in forest and scrub lands was similar, but the values differed between seasons in a similar manner for both land uses. The soil moisture stored in chena lands did not vary between maha seasons.

The seasonal contribution to the groundwater under each land use type was different. It was found to be about 7, 8 and 12 percent of the maha rains in abandoned chena, forest and chena under annual crops, respectively. The contribution to groundwater from yala rains was not apparent under all three land use types at mid-slopes positions of the catena studied (table 11).

This study indicates that forest and scrub jungle are similar in hydrologic behavior. They produce very little quantities of surface runoff and sub-surface flow. Thus, in the dry zone all lands protected by vegetation produce very low runoff under normal or average rainfall. The only condition in which the protected lands will produce appreciable runoff would be under very high rainfall, particularly when the rains are continuous for several days. Cleared chena land appears to be a major factor in the catchment runoff. The other land use types such as settlements, housing areas and rock knob plains, etc., will also behave similar to chena lands in generating runoff.

LAND TREATMENT TO ENHANCE CATCHMENT YIELD

Based on the data obtained from runoff plot experiments, it is inferred that catchment yield contributions from lands under forest and scrub jungle are very small. Most of the runoff is from cleared chena lands and lands with similar characteristic, such as Rock Out Crop areas, housing and settlement areas, etc. Further, with stabilization of rain-fed agriculture there will be more water conservation in catchment areas of minor and major tanks. The extraction of groundwater will also enhance the detention of rainfall within the source areas of major catchments. Enhancement of catchment runoff to improve the water supply to major tanks would be beneficial in the long term.

Rainfall in the maha season varies from about 600 mm to about 1,200 mm. Runoff from chena lands varies according to the intensity and quantity of daily rainfall. Total seasonal runoff from the chena is also variable; it depends on the seasonal rainfall. The maximum runoff that occurred during the study period is about 40 percent of the rainfall. Data from the same period show that lands with good surface cover yielded a very small portion of the rainfall as runoff. Land treatment reduces infiltration or surface detention or both. Therefore, it is possible to improve the catchment runoff by suitable land treatment. Experiments were designed to determine the possibilities of enhancing catchment yields.

Runoff plots (5m x 15m), with overflow divided tanks were constructed on a well-drained Reddish Brown Earth site. Five treatments with three replicates were tested under the randomized complete block design. Treatments were, surface soil compaction (mechanical), annual crops with soil conservation measures (small bunds and drains at 0.4 percent grade), scrub, grass cover and annual crops without soil conservation measures and treated with a rubber sealant.

The study shows that runoff from plots with compacted surface soil was distinctly more, compared to all other treatments. It is nearly 50 percent of the rainfall, during the early rainfall events. This indicates the possibility of increasing the surface runoff to tanks by allocating land areas with compacted surface soil. Any runoff reduced from conservation in stabilized rain-fed lands could be compensated for by soil compaction at selected locations in catchments.

The plots treated with the rubber sealant showed enhanced growth of grasses, which in turn reduced the surface runoff to very low values.

The runoff from plots with bunds and drains did not show much increased runoff compared to the plots without treatment. This appears to be due to the small size of plots; rainfall detention in small plots is not large enough to improve runoff with additional drainage or to capture the effect of bunds and drains on runoff generation. Therefore, firm conclusions cannot be drawn. To study the effect of high drainage densities, larger plots appear to be necessary.

The plots under scrub and grass produce negligible runoff and they are not effective for runoff generation. Higher runoff yields would be possible by increasing the drainage density without disturbing the vegetal cover. This concept was investigated.

This set of experiments carried out in maha 1993/94 shows that surface runoff from plots with higher drainage density is severalfold high as the surface runoff from plots of similar characteristics (table 15). Clearly, this appears to be a good method for improving the water supply to major and village tank systems. The surface runoff from chena plots can be further increased with suitably laid-out bunds and drains.

Table 15. Enhancement of runoff under scrub jungle with higher drainage density.

Rainfall (mm)	Runoff (mm)			Soil loss (kg/ha)	
	Untreated	Treated	Enhancement ratio	Untreated	Treated
59.5	2.0	17.3	8	-	-
17.2	0.1	2.7	27	-	-
12.0	0.1	0.6	6	-	-
60.7	2.7	16.0	5	19	48
11.7	0.1	0.2	2	0.4	2
42.0	1.3	8.0	7	12	80
13.8	0.3	0.3	0	0	0
76.0	2.1	10.4	5	32	52
82.0	2.0	13.4	6	30	53
24.2	0.6	0.9	1.5	0	0
25.2	0.4	0.6	1.5	0	4
46.0	3.5	7.0	2	0.8	-

$$\text{* Enhancement ratio} = \frac{\text{Runoff under treated plot}}{\text{Runoff under untreated plot}}$$

Specifications of

drains	depth	-	10-15 cm.
	width	-	30 cm.
	slope	-	0.4 percent.
	shape	-	parabolic.
	density	-	400 m/ha.
bund	height	-	25-30 cm.
	width (base)	-	30 cm.
plot	area	-	0.25 ha.

MICRO-CATCHMENT RUNOFF

The cumulative runoff depends on the cumulative rainfall and for most micro-catchments an exponential relationship of runoff rainfall was observed. Therefore, runoff from different parts of the study catchments, that is from sub-catchments, was varying on account of the special variability of the rainfall in the season. In seasons of low rainfall the runoff was substantially less compared to high rainfall seasons. The data also indicated that cumulative rainfall required to initiate catchment runoff is about 90 mm.

Table 15(a). Enhancement of runoff under chena with a higher drainage density.

Rainfall	Runoff (mm)			Soil loss (kg/ha)	
	Untreated	Treated	Enhancement ratio*	Untreated	Treated
78.2	8.6	17.8	2	-	-
24.8	8.3	12.0	1.5	-	-
31.2	7.1	10.1	1.5	-	-
59.5	11.9	20.1	1.8	64	153
17.2	1.2	2.5	2	-	-
14.5	0.8	1.7	2	-	-
60.7	29.1	33.1	1.1	-	-
11.7	3.8	5.9	1.5	18	23
42.0	14.8	16.8	1.1	41	55
76.0	27.7	28.0	0	149	135
82.0	22.4	22.5	0	-	-
24.0	6.2	7.3	1.1	-	-
25.2	2.4	3.3	1.3	40	60

$$\text{* Enhancement ratio} = \frac{\text{Runoff under treated plot}}{\text{Runoff under untreated plot}}$$

Specifications of

drains	depth	-	10-15 cm.
	width	-	30 cm.
	slope	-	0.4 percent.
	shape	-	parabolic.
	density	-	400 m/ha.
bund	height	-	25-30 cm.
	width (base)	-	30 cm.
plot	area	-	0.25 ha.

The runoff yields of selected sub-catchments were very low during the period of the study; that is from 1987 to 1992. The majority of small tanks in the Nachchaduwa Catchment did not spill in the maha seasons. Similarly, some small tanks in the Huruluwewa Catchment did not spill during the study period. The catchments of these small tanks, therefore, did not contribute any runoff to the two main tanks.

The relationship of the size of small tank catchments and tank capacity at full supply level appears to determine the frequency of spilling. The tanks whose ratio of catchment area to full capacity was less than 9 ha/ha.m did not reach full supply level, except on rare occasions (figures 9 and 10). Such tanks received 75 percent of the full supply only once in five to six years. The incidence of filling up to full supply level of small tanks whose ratio of catchment to full supply capacity was greater than 9 ha/ha.m was more frequent. Catchments of such tanks are able to contribute surface runoff to the major tank in the system.

Figure 9. Maximum storage per season.

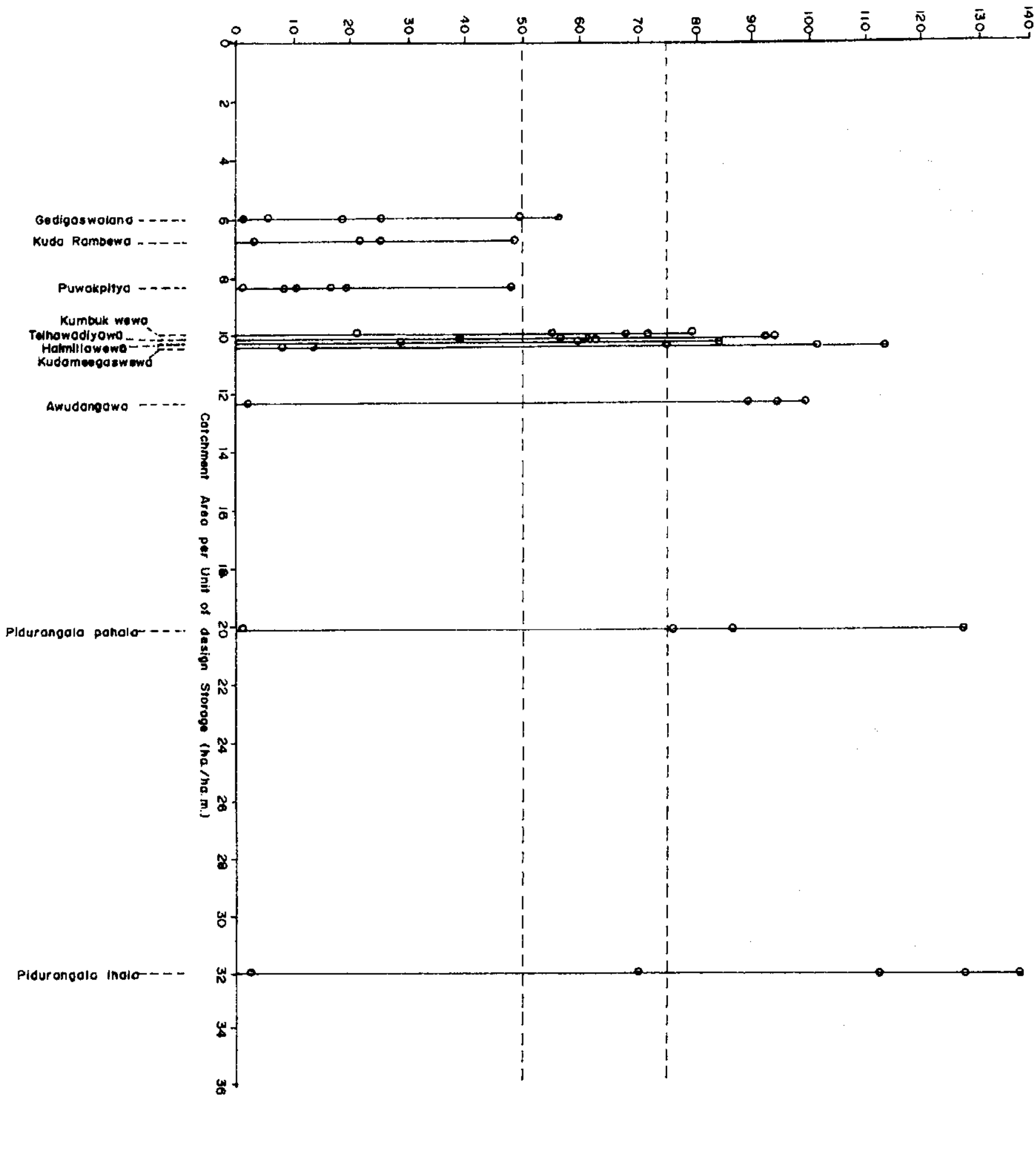
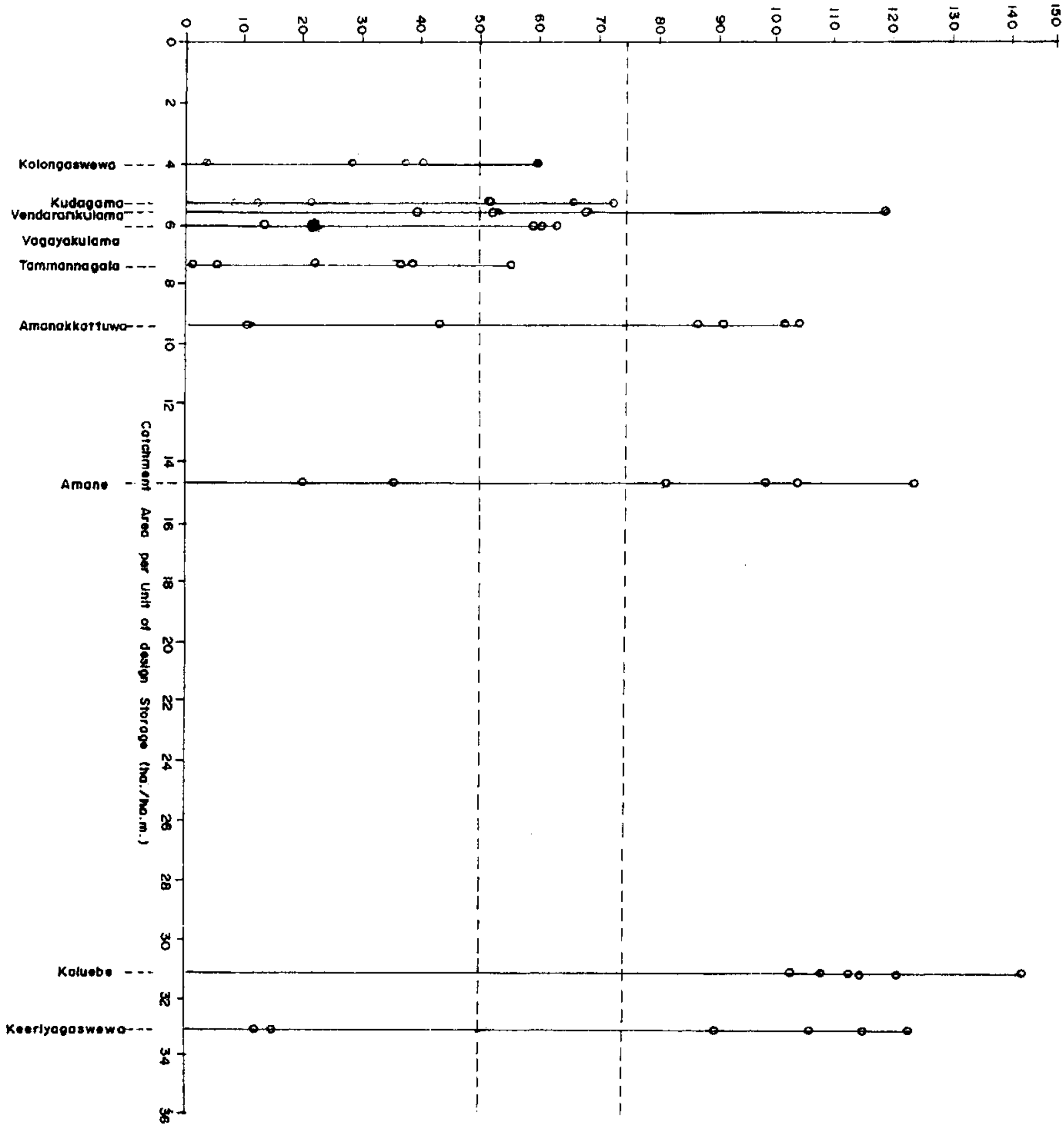


Figure 10. Maximum storage per season.



As the density of small tanks in a large catchment increases, the catchment size of the small tanks is reduced. At tank density at which the ratio of catchment size to capacity at full supply is 9 ha /ha.m or less, the frequency of spilling is so low that the extent of the catchment becomes noneffective for the major tank. Increasing the capacity of existing minor tanks, or constructing new minor tanks in major tank catchments, so that the ratio of catchment size to full supply capacity of that minor tank is reduced to 9 ha/ha.m or less, could make that part of the catchment noneffective as a source area for the major catchments studied and could adversely affect the water supply to the two tanks. Ultimately, the flow from minor tanks to a major tank in the downstream can be very small as most of that water is consumed in the minor tank command areas.

MICRO-CATCHMENT RUNOFF AND DEVELOPMENT OF A RUNOFF MODEL

Catchment runoff is largely influenced by such factors as the amount of rainfall, rainfall intensity and duration, topography, soil properties and land uses. Unlike other factors, land use is subjected to many changes arising from the agricultural and other development activities. Most of the time, these changes affect the tank water supply. Quantifying catchment runoff generated under different land uses and evaluating the integrated effect of all the land uses in a micro-catchment will provide the basis for planned land uses in the tank catchments. It is important to allocate lands for different uses so as to expect an appropriate runoff with a certain degree of stability.

To evaluate the influence of catchment use and management on the volume of runoff, development of a runoff model is the logical step. A simple model will have much practical value to the planners in their efforts to decide on tank sites and capacities, renovation priorities and appropriate catchment management. Therefore, in this study the focus was to develop a runoff model in terms of daily total rainfall, seasonal totals, catchment, land uses and other easily evaluated parameters.

A model based on water balance is extremely difficult to be developed as determining of various components of the tank water balance needs very sophisticated instrumentation. Also, the catchment runoff depends on factors such as land use in the catchment, rainfall, rainfall intensity, and antecedent soil moisture levels.

To develop a suitable runoff model several alternative steps were taken. Some of these have been presented in earlier reports. The most recent attempts are discussed here. Two main approaches are presented in this report. The first method adopted is a regression analysis procedure using the total runoff values and land use components. The second approach is a simulation of runoff from point sources or point runoff elements considering runoff as a time-dependent process related to processes such as infiltration, soil moisture depletion, changes in soil moisture storage and deep percolation.

Initially, a regression model was used with rainfall and extent of land under different uses as variables to predict runoff in two tank catchments. When the regression model was tested with small tank catchments, the runoff from very small tanks was greatly overestimated while that from others was underestimated.

Eighteen and twelve minor tanks were selected from the Nachchaduwa and Huruluwewa catchments, respectively. At least one cascade was selected to represent a sub-catchment. Some of the area capacity curves of those selected tanks were obtained from the Department of Agrarian Services or the Irrigation Department. Others were surveyed by the Land and Water Management Research Center and mathematical relationships were developed between tank water level elevation and the storage. The

water storage of the tank at any time was obtained by the relationships for water losses which were estimated through evaporation, seepage and percolation. Parshall flumes installed at sluices were used to measure water issues. In each season, the extent under different land uses was obtained using air photos with necessary modification based on field observations.

Rainfall was estimated by placing a series of rain gauges at pre-selected locations.

MODEL DEVELOPMENT

Model I

This model starts with total precipitation from a rainfall event and translates that rainfall into runoff volume according to an empirical relationship obtained from multiple regression analyses. This is an attempt to quantify the influence of the average soil type present throughout a micro-catchment, on landform conditions, as well as on vegetal cover and agricultural practices present in that catchment.

The mathematical form of the model adopted is as follows:

$$S = a + bRF + c(RF)^2$$

where,

S = Change of storage in village tank due to a rainfall event,

RF = Rainfall, and

a, b and c are constants.

The above model was fitted to two years' data collected in Nachchaduwa and Huruluwewa catchments and it was found that a satisfactory fit could not be obtained. This may be due to the differences in the two catchments and due to the fact that the model does not contain catchment area or land use variables. This deficiency was corrected in the model described below.

Model 2

In this model we assumed that a portion of the rainfall into each land area, assigned to some kind of use, contributed to the tank as runoff. We considered only the following land uses.

1. Forest—this includes forest in all stages of growth.
2. Chenal—and which is cultivated to upland crops in the season concerned.
3. Home garden.
4. Rice—Bunded rice fields.
5. Rock knob plains and erosional remnant.
6. Tank—the tank of interest; this makes a part of the catchment.

The mathematical relationship of the model is as follows.

$$S = Rf\,(aF + bc + cH + dP + eRKP + fT)$$

where,

S = Change of storage in tank resulting from rainfall (total catchment runoff), (m^3)
F = Forest area (m^2),
P = Rice area (m^2),
Rf = Rainfall (m),
C = Extent of chena (m^2),
H = Extent of home garden (m^2),
RKP = Extent rock knob plains and erosional remnants (m^2),
T = Extent of the tank (m^2), and
a, b.....f are coefficients (dimensionless).

Initially, we regressed the change of storage against the product of rainfall and areas of each land use (above model). However, we were unable to get satisfactory correlations. This may be due to the noninclusion of variables such as rainfall intensity in the model. In order to avoid such deficiencies, cumulative rainfall for the season was considered as the rainfall variable.

The following coefficients were obtained for Nachchaduwa and Huruluwewa catchments for different land uses in the model.

For Nachchaduwa Catchment

$$S = Rf\,(28.494F + 24.187C + 61.403\,P - 69.515\,RKP - 192.968T)$$
R^2 = 0.982, where R^2 = Coefficient of Correlation.

Inclusion of the homestead component of land use did not improve the R^2 value for the Nachchaduwa Catchment.

For Huruluwewa Catchment

$$S = Rf\,(0.716F + 0.947\,C + 8.828\,H - 58.926P + 6.108\,RKP - 7.701\,T)$$
R^2 = 0.995

Some observed and estimated storages are given below.

Nachchaduwa Catchment

Observed storage (cu.m)	Estimated storage (cu.m)	Percent overestimated/ underestimated
3,373	17,496	419
7,882	14,323	82
31,182	3,109	0.3
33,418	19,742	41
40,586	41,329	2
107,507	100,675	6
115,867	121,695	5
327,503	249,842	24
1,122,413	112,249	0.6

Huruluwewa Catchment

Observed storage (cu.m)	Estimated storage (cu.m)	Percent overestimated/ underestimated
1,727	1,727	0
3,214	11,094	245
9,539	8,247	14
21,970	24,854	13
30,429	26,448	13
31,163	28,249	9
75,635	76,153	0.6
109,844	109,893	0

In both catchments, it is seen that the model overestimated the storage in two tanks.

The reason for overestimation of the storage is not clear at present. We need to monitor very closely the storage of those tanks in future and check the catchments to estimate the reasons for this over-estimation.

Pooled data of the two catchments did not fit satisfactorily in the above model. This shows that the runoff characteristics of the two catchments are different. This can be expected because the geology and topography of the two catchments are entirely different. In the model, one year data of one tank made one observation point. Even if we monitored about 15 tanks in one catchment we had to discard some tanks because of bund breaches, damage to measuring devices by wild elephants and other reasons. Therefore, these models were developed with a limited data set. It is proposed to continue data collection for some more seasons in order to improve on the model.

The most serious problem with this approach is that the coefficients do not reflect the real ground situation. Even though the R^2 values are high, coefficients do not appear realistic. For example, in the Nachchaduwa model the coefficient for RKP cannot be true. However, in the Huruluwewa model the magnitude of coefficients obtained appears to be acceptable. Nevertheless, further examination of this

approach is required before this procedure can be accepted. Therefore, for the present, these two models are discarded.

Simulation Model

Dooge (1968) defined the term mathematical model as "any structure, device, scheme or procedure, real or abstract that interrelates in a given time frame an input, cause or stimulus of matter or energy or information and output effect or response of information, energy or matter."

The fundamental hypothesis of this model is that "at every point within a catchment, functional relationships exist between internal and surface water flow rates and are governed by hydrological parameters. These parameters are rainfall, infiltration, topography, soil type, etc.

An important feature of the above hypothesis is that its applicability is on a "point" basis. In order to apply this approach on a practical scale, the point concept is extrapolated and referred instead to a catchment "element," an area of definite size and shape. Thus, an element is defined to be an area or a part of an area within which all hydrologically significant parameters are uniform. The crucial concept is that an element must be sufficiently small so that arbitrary changes of parameter values for a single element will have only a negligible influence upon the response of the entire watershed.

A catchment to be modeled is assumed to be composed of "elements." A square shape element was chosen to ease the task of data file preparation and to facilitate computational convenience.

The micro-catchment is divided into cells of 5 ha in size. The land use composition of each cell is estimated from land use surveys. The cells are designated as either a stream cell or non-stream cell. A stream cell delivers runoff to the tank, whereas a non-stream cell transfers the runoff to an adjacent cell. To determine the runoff output from each cell runoff curves were developed based on the runoff plot data. It is this user supplied elemental data file listing the physical characteristics of each element of the watershed, which permits this model to simulate the unique behavior of any particular catchment hydrological component relationship characterizing water or pollutant production for which it needs only simulate the behavior of small areas. Parameter values are allowed to vary in an unrestricted manner between elements. Thus any degree of spatial variability within a watershed is easily represented. Individual elements collectively act as a composite system because of supplied topography data for each element delineating flow direction in a manner consistent with the topography of the catchment being modeled. Element interaction occurs, because surface and subsurface flow from each element becomes inflow to its adjacent element.

By the law of conservation of mass the simple hydrological relationship that exists in any given catchment element or a cell is as follows:

Input of water into one element = output of water from element + storage in the element.

The input of water to an element at the highest point in a catchment is the rainfall minus the interception by vegetation. The outflow is the surface runoff and deep percolation under gravitational force, part of which may be converted to lateral flow. The input of water to the next element at the lower level is the rainfall minus the interception by the vegetation plus the runoff from the element above. The outflow from the second element consists of deep percolation plus the surface runoff in to an adjacent element or to a stream channel which is expected to flow into a tank below.

The water balance of the earth's surface is a time-dependent relationship which must be computed as a continuous function in order to fully describe the catchment response.

Quantitative analysis of continuous response of the water balance is one objective of simulation modeling. The continuous solution of the water balance functions containing all the interacting components of the land phase is the basic approach to deterministic simulation.

By this method, knowledge and theory regarding the components of the land phase of the hydrologic cycle are integrated in a way to represent their continuous interaction.

COMPONENT RELATIONSHIPS

Flow Characterization

Mathematically, each element's hydraulic response is computed as a function of time by an explicit, backward difference solution of the continuity equation.

$$I - Q = \frac{dS}{dt}$$

where,

I	=	Inflow rate to an element from rainfall and adjacent elements ($m^{3/s}$),
Q	=	Outflow rate (m^3/s),
S	=	Volume of water stored in the element (m^3), and
t	=	Time (s).

Each grid element acts as an overland flow plane having a user specified slope and direction of steepest descent.

Rainfall

The net rainfall rate that reaches the ground surface is dependent on the rate of interception by vegetation. The maximum potential interception depends on surface cover type, which is as follows:

Natural forest	5 mm
Weeds	1.8 - 2 mm

$$Tin = (Sin + Si) - Smax\ (t-1)\ 1(t)$$

where,

Tin	=	Throughfall is rainfall in excess of interception storage capacity.
Sin	=	Interception storage at time (t-1)
Si	=	Increment to interception storage at time
Smax	=	Maximum interception storage capacity

The rainfall received at the soil surface is the throughfall. It can be argued that to record any throughfall the rainfall must exceed the maximum value of the interception. Therefore, in the computation, the effective rainfall is rainfall over 4 mm for the forest and scrub, and over 1.8 mm for chena.

Infiltration

The infiltration relationship that was developed by Holtan (1961) and Overton (1965), in a dimensional homogenous form can be expressed as:

$$Fmax = Fic + A \frac{P *(PIV)}{TP}$$

where,

Fmax	=	Infiltration capacity with surface mandated
Fic	=	Final or steady sate infiltration capacity
A	=	Maximum infiltration capacity in excess of FC
TP	=	Total volume of pore space within the control depth
PIV	=	Volume of water that can be stored within the control volume prior to its becoming saturated, and
P	=	Dimensionless coefficient relating the rate of decrease in infiltration rate with increasing soil moisture content.

Antecedent Soil Moisture

The infiltration equation in this model is based on the moisture content of the soil. Since the infiltration rate will be much greater when the soil is "dry" than when it is "wet," it is crucial that the correct antecedent moisture content be used when simulating actual situations.

A Simple Moisture Balance Approach to Determine the Antecedent Moisture Content in Each Soil

The form of the moisture balance equation is

$$Asm = Asml + Rain - Et - RO - Perco,$$

where,

Asm	=	Antecedent soil moisture,
Asml	=	Last known (initial) soil moisture,
Rain	=	Daily rain,
Et	=	Evaporation,
RO	=	Runoff, and
Perco	=	Percolation.

In this equation, all units of measurement are in mm or cm; percolation refers to drainage of gravitational water (water in excess of field capacity).

The following conditions, developed by the studies conducted, were used to estimate the antecedent soil moisture condition of each land use type.

a) The depth of the soil layer that influences the moisture content is equal 100 cm.
b) The evaporation rate is one half of normal on days that have rainfall of 5 mm.
c) The soil drains down to the field capacity within 0.5 day at the steady state infiltration rate in chena land.

    2 days - in forest land
    1 day - in abandoned land

d) When the soil moisture content reaches the wilting point no additional moisture is lost due to Et.
e) RO generation for different rainfalls, varies according to the antecedent moisture content and the amount of rainfall.

From runoff plot data rainfall retained in any element (cell) is estimated corresponding to the antecedent soil moisture condition prevailing on the day of rainfall. Rainfall or throughfall minus the amount retained in the cell is taken as the output from the cell.

Tables of runoff values for different storms under different land uses were prepared.

Inferences from this information are as follows:

Forest

a) Runoff is not generated for rainfall less than 10 mm.
b) Runoff from rainfall in the range 10-25 mm for antecedent soil moisture range 140-160 mm is 0.225 percent.
c) Runoff from rainfall in the range 25-50 mm for antecedent soil moisture range 120-200 mm is 0.35 percent.
d) Runoff from rainfall in the range of 150-200 mm for antecedent soil moisture range 60-120 mm is 0.2 percent.

Chena

a) No runoff is generated for rainfall less than 5 mm for antecedent soil moisture content less than 140 mm.
b) Runoff from 5 mm of rainfall for antecedent soil moisture content 140 mm is 2 percent.
c) Runoff from 25-50 mm rainfall for antecedent soil moisture range 80-120 is 3 percent; for antecedent soil moisture content 120-140 it is about 5 percent.

The runoff (RO) that enters into the stream elements will be added to the tank storage. This process will be simulated up to the final day of the maha season.

The stored water in the tank will be corrected to make an allowance for evaporation and seepage and percolation losses.

Finally, the measured tank inflow and net storage values will be checked with the simulated values.

This simulation model was developed and tested. The data input for the model is daily rainfall, land use of each cell, the flow direction and the coding of the cell type. Again, the model is not fully predicting the actual runoff. Further study would be required to test the model.

The problem with the simulation model is that the data set is inadequate to develop the runoff curves. Further studies would be needed to test this model.

Further, we would like to study the tanks for which the predictions deviate greatly from the actual values in order to find out additional variables which are responsible for this behavior.

Finally the measured tank inflow and net storage values will be checked with the simulated values.

Simulated and Computed Runoff

Tank: Gedigaswewa

Year	Calculated in ha.m	Simulated in ha.m
1987/88	12.4	2.1
1988/89	27.9	13.4
1989/90	59.8	66.3
1990/91	48.9	47.8
1991/92	35.8	35.9

Tank: Indigaswewa

Year	Calculated in ha.m	Simulated in ha.m
1987/88	15.7	1.00
1988/89	35.2	50.55
1989/90	75.3	50.75
1990/91	61.5	33.41
1991/92	45.1	23.69

Tank: Puwakpitiya

Year	Calculated in ha.m	Simulated in ha.m
1987/88	23.82	24.01
1988/89	32.12	9.96
1989/90	54.21	50.05
1990/91	50.19	45.61
1991/92	39.58	27.52

Tank: Kumbukwewa

Year	Calculated in ha.m	Simulated in ha.m
1988/89	101.37	60.16
1989/90	121.03	85.85
1990/91	120.68	86.00
1991/92	112.59	110.21

Tank: Awudangawa

Year	Calculated in ha.m	Simulated in ha.m
1987/88	51.87	82.65
1988/89	44.14	38.10
1989/90	99.93	158.32
1990/91	112.81	183.09
1991/92	84.15	119.28

Tank: Kudameegaswewa

Year	Calculated in ha.m	Simulated in ha.m
1987/88	29.23	30.08
1988/89	24.16	10.82
1989/90	54.10	95.43
1990/91	51.96	122.20
1991/92	47.31	79.43

Tank: Pidurangala - Thalawewa

Year	Calculated in ha.m	Simulated in ha.m
1987/88	26.0	36.55
1988/89	28.6	10.71
1989/90	60.0	97.12
1990/91	51.0	98.58
1991/92	43.8	44.01

Tank: Pidurangala - Pahalawewa

Year	Calculated in ha.m	Simulated in ha.m
1987/88	31.4	28.09
1988/89	31.0	11.95
1989/90	69.8	97.76
1990/91	63.0	98.58
1991/92	53.4	44.01

Tank: Kuda Rambewa

Year	Calculated in ha.m	Simulated in ha.m
1988/89	67.58	60.83
1989/90	80.68	69.98
1990/91	80.45	65.01
1991/92	75.06	91.14

Tank: Halmillewawewa

Year	Calculated in ha.m	Simulated in ha.m
1988/89	83.82	23.30
1989/90	118.66	95.60
1990/91	130.71	110.10
1991/92	110.97	77.94

Tank: Telhawadiyawa Wewa

Year	Calculated in ha.m	Simulated in ha.m
1988/89	104.40	57.40
1989/90	143.77	165.96
1990/91	157.49	112.28
1991/92	131.06	135.88

Many of the predicted values are very close to the measured and calculated values of runoff. However, there are other values that are quite different to the calculated values from the data. There is a need to include some of the other land types such as rock knob plains and determine the runoff curves for them. Therefore, further development of the model may help to predict runoff more accurately.

The simulation model may appear to be much better for prediction of surface runoff yield in micro-catchments compared to any regression model. Further studies are recommended.

CONCLUSIONS

1. Seasonal average rainfall decreases in the general direction of northeast to southwest. The lowest rainfall is in the upper catchments of both Nachchaduwa and Huruluwewa. Rainfall received in the Nachchaduwa Catchment is less than that in the Huruluwewa Catchment.

2. The cumulative runoff varies exponentially with the increase in cumulative rainfall during the season. As the seasonal total rainfall varies in different sub-catchments, the runoff yield from different parts of the catchments also varies.

3. The initial rains do not produce runoff. Surface runoff commences when the cumulative rainfall is about 90 mm in the maha season.

4. The surface runoff from chena (cleared area) is much higher than from the forest and scrub lands. Measurement of runoff from experimental plots indicates that most of the runoff collected in minor tanks is from the cleared areas.

5. Soil loss from cleared lands is about 9,000 kg per hectare per annum. The soil loss rate from chena declines very rapidly as the crop canopy develops covering the soil surface. Soil losses from forest and scrub lands are negligible.

6. Forest and scrub lands have similar hydrologic properties. Both these land use types generate very low runoff under average rainfall conditions. However, under prolonged rainfall conditions they promote temporary saturation of surface soil and under very high quantity and intensity of rainfall, the forest and scrub may produce substantial surface runoff.

7. Nearly half of the maha rainfall is consumed by the natural vegetation within the season itself. The part of the rainfall that is stored in the soil profile during mana and the total yala rainfall are consumed in the dry season. Soil moisture extraction by the natural vegetation is highly dependent on the soil moisture status. When the soils are wet/near field capacity water consumption by the vegetation is about 6 mm/day even in the maha season. With the drying of soil, moisture extraction declines very rapidly and it drops to values as low as 0.1 mm/day.

8. In-situ water balance shows that water available for deep percolation to recharge groundwater and for runoff is very small. It ranges from 7 percent to 12 percent of annual rainfall depending on the land use type.

9. Minor tanks that have their catchment area to full capacity ratio of 9 ha per ha.m or less attain full supply level only in a very few seasons. Some tanks reach full supply level once in six

seasons (years). Tanks having high values for this ratio, about 20, are found spilling over annually.

10. Irrigation potential of minor tanks whose ratio of catchment area to full supply capacity is 9 ha per ha.m or less is very poor, because of irregular and uncertain filling.

11. Catchment areas of minor tanks whose ratio of catchment area to full supply capacity ratio is 9 ha per ha.m or less are not effective as source areas for major tanks, if such minor tanks are within major tank catchments. Runoff yield from those minor catchments do not provide any water to the major tanks. Drainage from command areas of these minor tanks rarely reaches the major tanks.

12. Minor tank density in Nachchaduwa is high. There are a large number of tanks whose ratio of catchment to full capacity is less than 9 ha/ha.m; therefore, the effective catchment area is less than the area enclosed by the catchment boundary.

13. Runoff models based on multiple regression analysis do not appear realistic. The relationship of rainfall and runoff does not have regression coefficients that can explain the physical processes.

14. Simulation models based on the processes show promise. However, further studies are necessary to develop a relationship that can account for all the runoff notwithstanding the rainfall variability.

15. Compacted soils produced 60-70 percent more runoff than what chena/cleared land yielded with similar quantities of soil loss. This effect was found to last for more than one season.

16. Increasing drainage density improves the surface runoff and thereby tank water supply.

RECOMMENDATIONS

1. Do not increase capacities of minor tanks in major catchments.

2. Restoration of minor tanks should be limited as the tank densities are already high.

3. Restoration or rehabilitation of tanks whose ratio of catchment area to full capacity is 9 ha/ha.m or less is not recommended.

4. Soil compaction in selected areas of the catchment may be considered for enhancing runoff.

5. Although forest and scrub jungle yield very little runoff, these vegetation types should be retained for other environmental reasons.

6. Improvement of drainage density improves runoff from forest areas as well as scrub and cleared lands.

7. Controlling soil moisture losses from chena in the yala season by creating conditions to prevent ET losses by unwanted vegetation will improve the hydrology in the tank ecosystem.

Part II

Water Management in Nachchaduwa and Huruluwewa Schemes

INTRODUCTION

VERY HIGH PRIORITY has been given to the development of water resources for irrigation with a view to achieve economic progress. Providing irrigation facilities was considered a prerequisite for human resettlement in the dry regions to achieve sustained growth. However, many of the older irrigation development projects in Sri Lanka have failed to achieve the intended levels of productivity and efficiency of irrigation water utilization. This is attributed to poor management of irrigation water both at the system level and at the farm level. Hence, heavy public investments made on these irrigation development projects have been greatly underutilized. Therefore, a study was planned with the following objectives to investigate the existing system of irrigation water management in two irrigation schemes.

OBJECTIVES

1. To identify technical and socioeconomic constraints which limit production and lower effective utilization of irrigation water in major irrigation schemes.

2. To develop alternative techniques for efficient on-farm water management for increasing productivity and efficiency of irrigation water utilization.

The following study was carried out to achieve the first objective.

METHODOLOGY

Three distributary channels from the head, middle and tail end of the main supply channel of Huruluwewa and Nachchaduwa irrigation schemes were selected. From each of the distributary channels three field channels were selected representing head, middle and tail-end regions. From each field channel three farm units were selected situated in the upper, middle and lower region of the channel for on-farm studies. The study was conducted in yala seasons of 1989–1992.

The following data were collected from each farm.

1. Total volume of inflow and outflow was measured using Trapezoidal flumes from selected farms.

2. Rainfall was measured using non-recording rain gauges.

3. Soil moisture was determined by the gravimetric method.

4. Crops were managed according to the recommendations of the Department of Agriculture and crop yields were obtained at crop maturity.

DISCUSSION

Given in tables 16 and 17 are the inflow, outflow and water use by the crops at different sections of the main channel, distributary channels and the field channels in Huruluwewa and Nachchaduwa irrigation schemes, respectively. The two schemes were under different cropping systems. The Huruluwewa Scheme was under lowland rice while the Nachchaduwa Scheme was under upland crops. For the simple reason that excess water does not affect the rice crop, farmers tend to get as much water as possible to their farm allotments. Therefore, the amount of inflow into a field is an indication of the water availability at the point of inlet. The inflow into a unit land area decreases from the head end towards the tail end along the main channel (table 16). A close examination of inflow and outflow data reveals that outflow is related to inflow. When inflow is more the outflow will be more and when the inflow is low the outflow will also be low. It is interesting to note that the outflow, which is overland flow is quite high; varying from 20 percent to 43 percent of the inflow. It must be noted that this amount of water ends in drainage ways. These values themselves illustrate the state of water management in this scheme. In an ideal water management program inflow into each field should be based on the ET requirement of the crop, and seepage and percolation rates of the soil in the area. A nominal allowance decided upon practical field experimentation can be allowed for overland flow (for unavoidable overflow loss).

The ET, seepage and percolation (field water use) data presented in table 16 were estimated by subtracting the outflow from inflow. However, it must be noted that the fields were not regularly checked to see whether the fields dried up at any stage. The water use of various fields is compared with recommended water use for different soil types in table 18. Except in field number D10 F4-455, in other fields these two values compare closely. However in field No. D10 F4-455 the lower water use than the recommended value shows that the actual seepage and percolation values are lower than the estimated 3 mm per day.

The yield values reported are comparable with average yield data of the major irrigation schemes.

Unlike in Huruluwewa, the inequality of water distribution in the main channel in Nachchaduwa was not very pronounced. This difference may be attributed to the difference in cropping systems itself. Competition for water by the farmers was less because excess water damages the upland crops. For this reason farmers' interference with the irrigation system may be less. However, it can be seen that inflow into the fields widely varied irrespective of the location of the field on the main channel, distributary channel or field channel. The water losses by overland flow was only 6 percent of the inflow into the field in the Nachchaduwa Irrigation Scheme compared to 33 percent at Huruluwewa. This too can be minimized if proper water application methods are selected. The main water application method used by many farmers was wild flooding.

The actual field irrigation water use was lower than the recommended field water requirement (tables 18 and 19). However, rainfall should have supplied the balance. Rainfall during the cropping season was 355 mm. The wide difference between actual water use and recommended water requirement for chili shows that this crop has been subjected to water stress.

Table 16. Inflow, outflow and water use by crops at different field locations with respect to distance from the source of water in the Huruluwewa Catchment.

(A)	(B)	(C)	(D)	(E)	(F)	(I)	(J)	(K)
Head	Head (1)	Head (3)	1920 (18)	600	31.3	1320	Rice	4052
		Mid (22)	1860	580	31.1	1280	Rice	5122
		Tail	2213	750 (33)	43.1	900	Rice	423
Mid (5)	Tail (34)	Mid (322)	2250	810	36.0	1440	Rice	3972
		Tail	2130	900 (324)	42.3	1230	Rice	5681
Tail (10)	Mid (9)	Head (401)	1770	357	20.2	1230	Rice	3280
		Tail (455)	1200	450	37.5	750	Rice	5012

A - Distributary channel location in main channel.
B - Field channel location in the distributary channel.
C - Field location in the field channel.
D - Inflow/unit area (mm).
E - Outflow (mm).
F - Percent outflow.
I - ET seepage and percolation (mm).
J - Crop.
K - Area of the study m^2.

Notes: Parentheses indicate the channel or field numbers.

Table 17. Inflow, outflow and water use by crops at different field locations with respect to distance from the source of water in the Nachchaduwa Catchment.

(A)	(B)	(C)	(D)	(E)	(F)	(I)	(J)	(K)
Head	Head (4)	Head (1)	437 (2)	32	6.7	440	Cowpea	3,920
		Mid (5)	469	20	4.2	450	Chili	4,120
Mid (9)	Head (2)	Mid (4)	552	15	2.8	507	Cowpea	3,620
Tail (11)	Head (1)	Head (1)	934	145	15.5	790	Cowpea	2,076
Mid	390	6 (4)	1.9	396			Pumpkin	2,662
		Tail (8)	562	32	5.6	530	Blackgram	2,150

A - Distributary channel location in main channel.
B - Field channel location in the distributary channel.
C - Field location in the field channel.
D - Inflow/unit area (mm).
E - Outflow (mm).
F - Percent out flow.
I - ET seepage and percolation (mm).
J - Crop.
K - Area of the study (m^2).

Notes: Parentheses indicate channel or field numbers.

Table 18. Actual irrigation water use, recommended field water requirement and rice yield on various soil types in the Huruluwewa Irrigation Scheme.

Farm No.		Soil type	Field actual water use (mm)	Field Water use (mm)*	Recommended Yield t/ha
D_1	F_3-18	D_1-RBE	1320	1295	4.50
D_1	F_3-23	D_1-RBE	1280	1295	3.65
D_1	F_3-33	D_1-LHG	900	1035	3.52
D_5	F_{34}-322	D_5-RBE	1440	1295	3.28
D_{10}	F_9-401	D_{10}.RBE	1230	1035	3.16
D_{10}	F_9-455	D_{10}-LHG	750	1035	2.52

* Estimate using Et of 665 mm and seepage and percolation rates of 7 mm/day for RBE soils and 3 mm/day on LHG soils.

Table 19. Actual field irrigation water use, recommended field water requirement and yield of the crops grown in the Nachchaduwa Irrigation Scheme.

Farm No.		Crop	Field water use (mm)	Recommended field water use [1] (mm)	Yield kg/ha	RF(mm)
D_4	F_1-2	Cowpea	440	700	1422.4	335
D_4	F_1-5	Chili [2]	2450	1750	1364.8	335
D_9	F_2-4	Cowpea	500	700	1066.3	335
D_{11}	F_1-1	Cowpea	780	700	1281.7	335
D_{11}	F_1-4	Pumpkin	390	N.A.[3]	N.A.	335
D_{11}	F_8-	Blackgram	530	700	1347.5	335

1 ET seepage and percolation.
2 For 150 day crop.
3 NA - data not available.

It was not possible to carry out the intended full program owing to the civil disturbances prevailing in the country in 1989. However, we could get some insight into the water distribution problems in the two irrigation schemes which were under different cropping systems. There was an inequality of water distribution in both irrigation schemes among the distributary channels and field channels. In the Huruluwewa Irrigation Scheme where lowland rice was the main crop, there was a trend of decreasing water availability from head end of the main channel to the tail end. However, in the Nachchaduwa Irrigation Scheme where upland crops were grown such a trend was not very pronounced.

Further study is necessary to find the reasons for the large amount of water loss as overland flow from rice fields in the Huruluwewa Scheme. Ways and means for this loss have to be identified for development of alternative water management strategies to enhance irrigation efficiency in these schemes.

The research during yala 1990 concentrated on testing two on-farm water management practices:

1. Top-to-bottom irrigation
2. Bottom-to-top irrigation

Essentially these two are basin irrigation methods. Only the way of irrigation is different.

Top-to-Bottom Irrigation

In this method the uppermost basins are irrigated first and, gradually moving downwards, the lowermost basins are irrigated last.

Bottom-to-Top Irrigation

In this method the lowermost basins are irrigated first and, moving upwards, the uppermost basins are irrigated last.

These two methods of irrigations have their own merits and demerits.

Five distributary channels from the Nachchaduwa Irrigation Scheme and four from the Huruluwewa Irrigation Scheme were selected. From each distributary channel, one field channel was taken for the study. Experimental plots were selected from one field from each field channel.

Four plots (basins) running towards the main slope made one experimental unit. There were two categories of plots namely, large (average plot size 360 m^2) and small (average plot size 144 m^2) plots in the Nachchaduwa Irrigation Scheme. Only one plot size was used in the Huruluwewa Irrigation Scheme.

Farmers managed the crops all by themselves. The researches were involved only in measuring the irrigation water. They instructed the farmers how to do the irrigation under the two methods. In experimental plots in Nachchaduwa, chili was cultivated while soybean was grown in those in Huruluwewa. The following data were collected:

1. Inflow into the basins at the inlet and out flow at the outlet using trapezoidal flumes.
2. Rainfall on the experimental site.
3. Soil moisture samples were taken from 15, 30, 50, 90 and 110 cm depths at regular intervals.

DISCUSSION

When the basin size is small the same amount of irrigation water was used in both the bottom-to-top and top-to-bottom methods of irrigation. However, when the basin size is large about 100 mm of more water was consumed for chili in the bottom-to-top method of irrigation under farmer management. This is due to poor leveling of the larger basins. In the top-to-bottom method of irrigation after keeping the water in the basin for the opportune time farmers let out the water to the lower basin. But in the bottom-to-top method of irrigation excess water is added to wet the higher parts in the field and this water is lost or let out to flow from the field. Higher outflow from the bottom-to-top method of irrigation than from the other method is evidence for this fact. In the Huruluwewa Irrigation Scheme, only smaller plots were used for the experiment. As in the case of Nachchaduwa, here too, similar quantities of water were used in the two methods of irrigation.

In both schemes, less water was used in the top-to-bottom method of irrigation than in the other method.

The method of irrigation does not seem to affect the yield of soybean or chili.

Soils retained more soil moisture in the profile when the bottom-to-top method of irrigation was used than when the other method was used. This is because farmers inundated the basin and kept the outlet

closed. But in the top-to-bottom method the outlet has to be kept open to take the water to the basins below.

All the farmers interviewed preferred the top-to-bottom method of irrigation to the other method. They cited high incidence of diseases, higher water loss and longer time required for irrigation as disadvantages of the bottom-to-top method of irrigation. Our data support the farmers' observations.

Less irrigation water is used in the top-to-bottom method of irrigation; it has no adverse effects on yield, saves water and is preferred by farmers. On the other hand, more moisture in the profile is retained when the bottom-to-top method of irrigation is used. Therefore, it may be possible for one to increase the irrigation interval. However, most of our irrigation schemes are designed for one-week rotations so that changing the frequency may impose problems on the irrigation system management. Therefore, under the present circumstances, the top-to-bottom method of irrigation is recommended as an on-farm water management practice.

RESEARCH FINDINGS AND CONCLUSIONS

Research findings from the above investigations are briefly outlined below.

a. There is equity of water supply at the head-end, middle and tail-end sections of the field channel located close to the head end of the main supply channel.

b. Water supply to fields at the tail end of the field channels (FCs) that are located at the tail end of the main supply channel is about 30-40 percent less compared to the supply available at the head and middle sections of the main channel.

c. Surface drainage losses from fields irrigated by FCs near the head end and middle sections of the main supply channel have been much higher than from fields irrigated by the FCs at the tail end of the main canal.

d. On average, the overland water loss from an individual farm unit is nearly 30 percent, while the average loss from a micro-hydrological unit is about 40 percent under rice cultivation.

e. Under farmer management, water application to other field crops in yala has had little loss of water as surface drainage. Total water applied is comparable to or sometimes even lower than recommended field water requirements.

f. Of the two methods tested under farmer management, the top-to-bottom method was found to be more suitable for unevenly leveled large plots. However, for smaller well-leveled fields, using the bottom-to-top method of irrigation can save more water and obtain uniform wetting. The top-to-bottom method requires less irrigation time than the other method.

g. To improve the efficiency of irrigating water under major schemes, one will have to pay much attention on system management, rather than on farm management.

Part III

Review of Laws Relating to Catchment Management

THERE ARE MANY Acts, Ordinances and Statutes relating to the use of lands and their management. A large number of regulations and orders gazetted under various Acts of Parliament are in force. These laws, rules and regulations reflect the government policies which have been implemented over decades. They involve very wide policy issues including economic, sociological and political considerations. By and large, the underlying principles of all land laws framed, at least after the country gained independence in 1948, have been (i) some protection of the resources, (ii) welfare of the people, and (iii) achieving economic growth.

In the present context, these land laws are examined with the view to ascertain their adequacy for proper management of tank catchments and to make recommendations.

Land use and land management practices have direct impacts on the catchment hydrology and consequently on the inflow to tanks and the stability of the tank water supply. The question of catchment management is so very important because in every reservoir catchment, whether it is large or small, there are human settlements and multiple land uses. For different uses land allocations adopted are ad hoc and are not based on any scientific data about the resources and hydrology.

The important items of legislation with reference to management of both state-owned and private lands are:

1. Land Development Ordinance (chap. 464)
2. State Lands Ordinance No. 8 (chap. 454).
3. State Land (claims) (inclusive of Amendments in 1983) Act, No.7 of 1979.
4. Land Resumption Ordinance.
5. Land Acquisition Ordinance No.60 of 1961 (inclusive of Amendments No.5 of 1964 and No.28 of 1964).
6. Land Grants (Special Provisions) Act, No.43 of 1979.
7. Land Reforms Law.
8. Soil Conservation Act No.25 of 1951.
9. Land Settlements Ordinance 1931.
10. Forest Ordinance (chap. 451).
11. Irrigation Ordinance (chap. 453).

12. Water Resources Board Act No. 29 of 1964.

13. Felling of Trees Control Act (chap. 452).

14. Land Use Policy Planning Act.

The Land Development Ordinance is a very vital enactment of the government, which in principle is a radical change in land policy in this country. This was the beginning of an attempt to pass on to the people the lands that were acquired by the British Crown with the passing of the Waste Land Ordinance.

The purpose and spirit of the Land Development Ordinance may be summarized as flows: It is to transfer the state-owned lands on a long-term lease (90 years), now converted to a grant, largely to the landless peasantry and on a limited scale to other classes of people in this country to practice agriculture. A system of shared control of the land resources is the basis to ensure protection of the peasant class from dispossession of their lands by anyone outside the peasant class. The individuals are given the right to farm according to their own ability within the framework of rules and regulations of other relevant ordinances such as the Irrigation Ordinance, the Agrarian Law, the Soil Conservation Act, etc.

The Land Development Ordinance is basically a set of regulations on how to alienate and develop state-owned lands. It has provision for the appointment of a Land Commissioner and the issue of permits and grants; and deciding how succession to alienated land would be governed, and what rights and what degree of ownership the recipients would have. This Ordinance gives the authority to the Land Commissioner or the Government Agent on his behalf to survey and demarcate any state-owned land for any of the following purposes: village expansion, village forest, village grass lands, any other use of the village, resettlements, protection of springs and waterways, soil conservation, protected forest, to set up infrastructure—government buildings and roads, etc., climatic and environmental protection, archaeological reserves, requirements of local institutions, urban development, alienation to certain classes of people and any other use in the interest of regional protection, conservation and development.

No permit holder is allowed to sell or mortgage the land (or any part thereof) alienated under the provisions of this Land Development Ordinance. However, a permit holder may lease an alienated land to an approved institution or a registered society but the institution or the society is not permitted to dispose such land to recover unpaid loan amounts and interest. It is only the Government Agent/Land Commissioner who has the authority to dispose of such land and recover the debts.

Presently, the Government Agent is authorized to issue a land grant to a permit holder if s/he is satisfied that the permit holder has occupied such land for a time longer than the prescribed period and that the said land is fully developed.

Action can be taken to cancel permits and remove a permit holder from occupation of state land only if the terms and conditions of the permit are violated. However, these terms and conditions emphasize payment of a prescribed land rent rather than land development for increasing land productivity and protection of the environment.

The State Lands Ordinance deals with the power of the state to sell, lease, grant or otherwise dispose of state lands. It seems to vest a great deal of discretion in the President in doing this, specially when the recipient is a private individual or institution. Section 14 of this Ordinance gives the President the power to mitigate or release any of the terms and conditions laid out in the original grant, which reflects the wide and undesirable nature of powers vested with the President in regard to alienation of state lands. Part V of the Ordinance gives power to local authorities to alienate land vested in them. The sanction of the Minister is sufficient for this purpose. Here too, there do not appear to have any uniform guidelines to determine when the local authorities could alienate such land.

The Land Grants (Special Provisions) Act is to provide for the transfer of state-owned land to any one over the age of 18 years. The President has the authority and discretion to execute the land transfer. The grantees do not receive absolute ownership of land alienated to them.

The Land Settlement Ordinance is to settle disputes of landownership between the state and individuals.

The Soil Conservation Act No.25 of 1951 deals mainly with the mitigation of soil erosion in the plantation sector, particularly the upcountry tea lands. The Act has provision to declare any part of a watershed as protected. The regulations passed under this Act relate to the application of soil conservation measures by private individuals and companies in tea and rubber lands under the supervision of Soil Conservation Officers of the Department of Agriculture within any area that is declared erodible.

The 13th Amendment to the Constitution has an impact on many of the statutes in force relating to land use. The subjects within the preview of Provincial Councils include agriculture and agrarian services and rehabilitation and maintenance of minor irrigation works. Interprovincial irrigation and land settlement schemes, state land and plantation agriculture are outside the purview of the Provincial Councils.

This Amendment also provides for the creation of the National Land Commission which will include representatives of Provincial Councils. Paragraph 3:3 provides that,

> *National policy on land use will be based on technical aspects (not on political or communal aspects) and the Commission will lay down general norms in regard to the use of land, having regard to soil, climate, rainfall, soil erosion, forest cover, environmental factors, economic viability, etc.*

The 13th Amendment to the Constitution, Paragraph 8, List III, the Concurrent List deals with the establishment and promotion of agro-linked industries, the establishment and maintenance of farms and supervision of private nurseries, soil conservation and plant post. Paragraph 17 deals with, inter alia, water storage and management, flood protection and planning for water resources development. Paragraph 18 deals with social forestry and the protection of wild animals and birds. Paragraph 33 deals with the protection of the environment.

Most of the laws relating to agriculture and land use will have to be amended in the light of the 13th Amendment to the Constitution.

An Act was passed to institute the Land Use Policy Planning Division in the Ministry of Lands, Irrigation and Mahaweli Development to ensure that in the future land use will be on a scientific basis. This division has been entrusted with subjects related to the development of a land resource database and the preparation of indicative land use plans.

One of the important issues being debated at present is landownership. There is one school of thought which advocates granting of absolute ownership of a good part of the state lands to the people. This view is put forward on the basis that 80 percent of lands in Sri Lanka is owned by the state as shown in the National Land Commission Report of 1987. The argument is, if the people do not have complete ownership of land and if they are unable even to pass it on to their children will they preserve and care for these lands and use them in an environmentally sound manner?

The assumption that 80 percent of lands in Sri Lanka is owned by the state is debatable. Nearly all good agricultural lands are either privately owned or under a shared control arrangement. All lands alienated to the peasant class are under the control of the occupants of such land except that they are not permitted either to transfer such lands to anyone outside the peasant class or to subdivide them. It has been the policy of all governments to alienate lands to the people who till the soil.

On the other hand, sufficient security of tenure for farmers to utilize specific areas of land over an extended period reduced the temptation for exploitative land use. Security of tenure is usually assured by ownership title, but other mechanisms are available to provide effective security. Settlement schemes offer de facto security, as do various types of traditional tenancy. Security of tenure alone is not sufficient to ensure that farmers will make economically and environmentally sound decisions.

RECOMMENDATIONS

There are too many Ordinances, Laws and Statues in relation to land tenure, use and management, which make interpretation and implementation of them extremely difficult. The powers vested with the President are too wide and perhaps undesirable. Current land laws allow the President, Land Commissioner/Government Agent and Provincial Council to make independent decisions on the transfer of lands to any one individual or institution. The land management is entirely under the control of the Provincial Councils. Many of the statutes deal with the alienation of state land and its development, acquisition of private lands by the state, the recovery of encroached state lands, land settlements, etc. A detailed study is necessary to analyze whether and to what extent these statutes are in conflict with each other. At the moment, Sri Lanka lacks a comprehensive statute relating to land use and it is better to formulate one. Most of the ordinances relating to use and management of lands were framed with the object of collecting revenue for the government and not with the intention of preserving the land resources for posterity or of developing for enhanced productivity.

Encroachment on state lands is a major problem affecting proper catchment management. In spite of all statues in force, the government has not been able to protect catchments from extensive clearing. There must be adequate provisions in land laws to deal with this problem. Regularization of encroachments once the land is degraded through poor care and exploitative use by the encroacher is not conducive to proper catchment management and it will not discourage further encroachments.

There is no adequate provisions in the ordinances and statutes or mechanisms to manage catchment lands as source areas to ensure water supply to tanks in the dry zone. The poor catchment management is attributed to the uncertain tenure arrangement for lands in tank catchments. This is only true in the case of unregularized encroachments. The impact of not having absolute ownership of lands on the catchment degradation is not adequately examined. Applied research on existing land tenure arrangements is necessary before definite recommendations for granting of outright ownership could be made.

One of the facts adversely affecting water supply to larger tanks is the detention of water in catchments by renovation and increasing the capacities of other minor tanks or construction of new minor tanks. According to the 13th Amendment, the Provincial Councils may increase the catchment detention by any of the above methods at the expense of the water supply to interprovincial systems. There must be clear directives to the Provincial Councils to obtain clearance from the government before any water detention measure is constructed in the catchments of large reservoir systems or interprovincial systems.

A set of comprehensive policy guidelines on land use for the country, based on scientific data on land and water resources should be established.

At present, the groundwater is extracted on an uncontrolled and ad hoc basis. As the shallow aquifer is fed by the local rainfall that percolates down in tank catchments and also by the deep percolation from the tanks, excessive extractions would adversely affect the tank water supply. Legislation is necessary to regulate the extraction of groundwater so that the tank system is not adversely affected.

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