GUIDANCE PACKAGE

FOR

WATER DEVELOPMENT COMPONENT

OF

SMALL TANK CASCADE SYSTEMS

Initial Environmental Evaluation (IEE) Report
Prepared by
Sri Lanka Field Operations (SLFO) of IIMI
for
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GUIDANCE PACKAGE FOR WATER DEVELOPMENT COMPONENT OF SMALL TANK CASCADE SYSTEMS

1. INTRODUCTION

1.1 Preamble

The Government of Sri Lanka together with the International Fund for Agricultural Development (IFAD) and the Swedish Development Agency (SIDA) are in the process of preparing a Participatory Development Project for the North Central Province of Sri Lanka. As part of the preparatory process, IFAD has decided to undertake an Initial Environmental Evaluation (IEE) to provide a preliminary assessment and guidelines for assessing the Water Development component of the Project by entrusting a consultancy contract to the International irrigation Management Institute (IIMI) to carry out this study.

The Study is based on the analysis of information and data available with relevant agencies and from research reports, staff appraisal reports and post-project evaluation reports of irrigation rehabilitation programmes pertaining to the Anuradhapura District in the North Central Province (NCP). In addition, data was collected through field survey and discussions with stakeholders, agency officials and other interested parties. Also for selected sub-watersheds rapid appraisal of land and water resources of minor tanks, mapping the catchment and command areas and looking at the issue of catchment, waterspread (tanks) and the command as a unit for surface and ground water potential was carried out.

The preliminary assessment involved:

- Characterization of watersheds and selection of five typical sub-watersheds;
- Mapping of tank cascade system on sub-watershed basis and assessment of catchment land use pattern, drainage density, etc;
- Collection and analysis of data for selected tanks including: size distribution; catchment area; tank storage capacity; waterspread area; command area; groundwater potential; present groundwater extraction and tank inflow; and spatial and temporal characteristics of rainfall in the NCP;
- Estimation of the present and proposed use of tanks' water for irrigation and other purposes;

- Estimation of the present and proposed use of open dug well water for irrigation and other purposes;

- A water balance study based on the existing data for the present and proposed demand for water considering an individual tank as well as sub-watershed consisting of the cascade as the bank unit.

The study analyzed: both quantitative and qualitative data for typical tank cascades to identify the factors contributing to and constraining from improving the tank storage of minor tank systems; representative cascade systems to explore the various factors that might affect water resources development under the Project (including the interaction between tanks), upstream - downstream relationships and the impacts of agrowells; and determined groundwater resources from available data, indicating areas most suitable for further development and the present status of groundwater quality trend and the need for monitoring. It also studied the effect of various design parameters on the potential cropping intensity of a tank through a simulation model developed under this consultancy **(see Section 5.4 and Annexures 4 and 5 for details).**

The main outcome of this consultancy study is a detailed guidance package for selection of minor tanks for rehabilitation in the dry zone of Sri Lanka.

The tank rehabilitation approach proposed by this consultancy is different to the approaches that have been adopted hitherto. The new approach stresses the need for the catchment, tank, highlands, command and drainage area of a tank being considered the mosaics of a geographically and socially integrated, micro-watershed unit for integrated rural development planning and implementation under which tank rehabilitation may be considered and implemented for proper management of land and water resources within that watershed unit in order to improve the income and well-being of the people.

In addition, this consultancy suggests:

- a framework for characterizing tank cascade systems in the NCP;

- guidelines, including indicators and criteria, for characterizing tank cascades and evaluating their potential;

- guidelines, including indicators and criteria, for surface water extraction, selection and design of tanks for rehabilitation.

- a basis for determining the nature of rehabilitation and intensity of financial investments (pro-rata cost) that could be set apart for different rehabilitation interventions;

- criteria for agrowell development both in upland and lowland areas;

- design parameters that are to be considered for water resource development and tank rehabilitation;

- procedure for simulation modelling of tank cascades and individual tanks, including model framework and an operation manual that can be used for simulating various rehabilitation scenarios;

- guidelines for technical, water resources, management and socio-economic analysis of tanks contesting for rehabilitation; and

- an implementation strategy for the water resource development component.

The remainder of this chapter explains some of the terminologies and parameters used for developing guidance package for rehabilitation.

1.2 Tank Cascades

In the small valleys of the undulating dry zone terrain, less rapidly moving water cascades from the crests of the low ridges to the keels of the small valleys are intercepted with man-made small and narrow earth bunds of low elevation, to create tanks big and small. The small tanks are constructed in the upper slopes of the small valleys and the bigger ones are constructed in the keels of the valleys. furthermore, it is to be noted that the tanks in a keel usually become bigger and bigger as one moves downstream a valley. Water in these reservoirs in a valley, cascades from one to another, starting from upstream towards downstream into a considerably large reservoir far below and finally the volume of water spilled over from that large reservoir at the far end enters a large stream usually termed 'Oya'.

A perusal of historical documents lead us to conclude that the cascade concept had been well entrenched in the minds of the traditional farmers and water resource managers from ancient times.

One of the cardinal strategies adopted in tank construction in a cascading valley seems to be the strict adherence to:

(a) have an adequate volume of water in every tank of the settled villages in a cascading valley even in a year of below average rainfall;

(b) institute a regulated flow of water from one tank to another downstream, avoiding sudden influx of large volumes of water in order to minimize the risk of tank bund breaching; and

(c) have some reservoirs in reserve, as '<u>Olagama</u>' tanks in the head-end portions of the valley to meet irrigation shortfalls of the main village fields as well as <u>'Godawalas'</u> as water holes for wild animals and village cattle.

In tank cascades, bunds of upstream tanks were never allowed to be raised to impound more water than originally intended to. An ad-hoc bund raising has two negative consequences -- submerging tail-end fields of the immediate upstream village and the denial of some water to the tank downstream of it, causing irrigation water shortages. Thus, spill level, diameters of irrigation sluices, as well as the levels of their placement (sill levels), bund top levels, release of water per field irrigation were all done having in mind the entire network of tanks in a cascading valley.

In addition, the hydraulic inter-connection of groundwater flow from one tank to another and irrigation return flow from upstream command to downstream tanks make it more important that the tanks in a cascade be studied holistically to identify their hydrologic inter-connectors. Therefore, it is argued that for any improvement of tanks in a cascade, the tank cascade system should form the primary unit for investigation of its land and water resources potential and constraints and their hydrological and socio-economic interactions. Also, the word 'Cascade' refers to the inter-connected tanks while sub or micro watershed refers to the land mass surrounding the cascade contributing to its run off.

1.3 Cropping Intensity (CI)

Village tanks (also called minor tanks) are primarily used for lowland irrigated paddy cultivation during the wet season that corresponds with the higher rainfall -- north-east monsoonal season (Maha season). In those years where excess water is available, a second paddy crop/other field corps will also be attempted, although this will be in a limited command area. Use of groundwater through agrowells is also increasing during the Yala season. Groundwater development through agrowells in both uplands in tank catchments and uplands and lowlands in tank commands has been rapidly increasing over the last few years. In recent years, it has been stated in a number of publications that hydrology of many cascades are such that they are not able to meet the demand of already developed paddy lands. This is attributed as one of the main reasons for low cropping intensity. In addition, there are number of other factors contributing to low cropping intensity. Some of the important ones are:

- the physical condition of the tank and its distribution system is not conducive for effective water use;

- socio-economic constraints such as:

    * labor and resource shortage,
    * fragmented land holding and preoccupation with chena cultivation.

- institutional and management constraints;

- development of command areas much higher than what the tanks can feed.

One of the issues that came up for discussion during this consultancy is, what parameter or parameters will be used to select a tank or a set of tanks in a cascade for rehabilitation and modernization. After a careful analysis of existing data and a series of discussions with implementing agencies and users, it is decided to use the Maha cropping intensity as an indicator to select a tank or cascade for rehabilitation. This is justified by the fact that the use of annual cropping intensity does not make much sense as only a very limited area is cultivated during the dry (yala) season in the NCP. Cropping intensity is one factor which integrates the hydrological, technical and socio-economic components of a tank system and therefore, it is an ideal parameter to judge whether the tank needs rehabilitation or not.

The Maha cropping intensity is defined as the area irrigated during the Maha season divided by the total command area under each tank. The total area includes old areas (Puranawela), subsequently developed areas (Akkarawela) and encroached areas. Only Maha irrigated area is considered because there is very little Yala cultivation under these tanks except for one or two years out of ten when the rainfall is excess.

1.4 Actual Average Cropping Intensity (CI) for an Individual Tank

The actual average cropping intensity (CI) for an individual tank is computed based on the information collected from the stakeholders at the village level. Both Maha irrigated area and total command area of the tank were collected through a questionnaire for the last five seasons and a time-averaged CI is computed based on the five Maha seasons data. This procedure allows us to cross check the authenticity of data used for computation.

1.5 Weighted Cropping Intensity for a Tank Cascade

In a given Cascade, the CI of individual tank generally varies. Computing an arithmetic average of these CIs will lead to a skewed cropping intensity for the cascade as a whole. Instead, a weighted average CI, weighted with command area would give a better representation of Cascade CI. The weighted cropping intensity for the cascade is computed by weighing the individual tank average CI by the fraction of the command area under the tank and adding for all the tanks under the Cascade.

In other words, if CI_i is the average CI of individual tank, a_i is the command area of that tank, then weighted CI_w of tank cascade is given by

$$CI_w = \frac{\sum_{i=1}^{N} CI_i \cdot a_i}{\sum_{i=1}^{N} a_i}$$

Where N refers to the total number of tanks under the Cascade.

It is to be noted that while individual tank cropping intensity is time averaged value, the weighted CI for a tank cascade is both time and space averaged. Another way of computing weighted cropping intensity is to divide the total maha cultivated area of the cascade by the total command area of the cascade.

1.6 Potential Cropping Intensity

The potential cropping intensity for each tank in a cascade is determined using the simulation model developed under this consultancy and described in **Annexures 4 and 5.** The potential CI for individual tank will vary depending upon the level of investment and management effort put in managing the system. For a given hydrological condition and assumed parameters such as seepage and percolation (S and P), drainage return flow coefficient, rainfall, crop water requirement and irrigation efficiency one can generate a set of areas that can be irrigated for different levels of investment and management efforts. This will then lead to a set of potential CI for different tanks.

For example, rehabilitating the tank proper, modernizing its distribution system and strengthening farmers' involvement through participatory management would lead to a greater potential cropping intensity than just rehabilitate the tank proper. These two situations require different levels of investment and management efforts.

1.7 CI as an Indicator for Tank Rehabilitation

Having computed the actual and potential CI for an individual tank, the difference between the two represents the gap which can be bridged through rehabilitation and modernization measures. These measures may include physical (technical), managerial and institutional. The Chapters that follow discusses the process to be adopted in identifying the measures to be adopted for bridging the gap between actual and potential CI and a package for implementing such strategy.

2. PRESENT PROCESS OF TANK SELECTION AND DESIGN FOR REHABILITATION

1. In Sri Lanka, the term 'tank rehabilitation' usually means one of the following options.

   (a) Restoration of an abandoned, non-working, ancient tank together with development of command area under the restored tank.

   (b) Restoration of a non-working, ancient tank, where there are already developed command area and settlement under the tank, but cultivation in the command is not fully done due to lack of irrigation system or the tank bund being breached or both.

   (c) Improvements to a working tank to increase the existing storage capacity and expand the existing command area of the tank. The typical improvements may include: raising the tank bund and spill; improvements to the existing sluices and the improvements to existing irrigation system.

   (d) Refurbishment of an existing working tank without increasing the existing storage capacity or expanding the command.

2. About four decades ago, the minor tank rehabilitation in the country was mainly categories (a) and (b) above in nature. Later the emphasis of rehabilitation shifted from category (a) and (b) to categories (c) and (d), particularly under the Village Irrigation Rehabilitation Project (VIRP) and the National Irrigation Rehabilitation Project (NIRP).

3. At present, irrigation tanks are selected for restoration[1] or rehabilitation[2] from 'interest lists' prepared and maintained by the Irrigation Department (ID), based on compilation by the ID, Agrarian Services Department, and the Provincial Irrigation Department. The priority for selection of tanks is usually determined based on the pressure brought in or interest shown by the pressure groups and others.

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[1] For this note, 'Restoration' means bringing an abandoned minor tank to working conditions by filling the breaches in the bund, providing spills, sluices, irrigation system. people under the command.

[2] For this note, 'Rehabilitation' means repairing or improving an existing working tank to improve its hydrological and agricultural performance.

4. Once a preliminary list of tanks is prepared for the rehabilitation consideration, each tank is appraised by a Technical Officer of the Irrigation Dept. or Provincial Irrigation Dept. This initial appraisal is usually called Preliminary Investigation Survey (PI Survey).

5. The purpose of this PI survey is to assess initially the technical viability and economic feasibility of the tank for rehabilitation based on limited data and information. The survey is supposed to find: hydrology of the tank; spilling history; cultivation history; and physical status of the tank components and its irrigation system. The PI Survey procedure is the compulsory first step in the tank rehabilitation process. The technical officer is expected to assess the: hydrologic potential of the catchment; area and/or additional area that can be brought under cultivation after rehabilitation; availability of construction materials in the close vicinity to the tank; impact of tank restoration or rehabilitation on the other tanks in the watershed, etc. The last aspect is usually the least attended one in the PI study.

6. It is worth noting here that the standard format used for reporting data and information of the PI survey is one which was developed by the Irrigation Department a few decades ago. This format is still used even today for reporting the data and information of the PI survey, although, the notion and scope of rehabilitation as well as socio-economic conditions under which minor tank rehabilitation has to be considered and implemented has changed significantly. A more rational survey approach for diagnosing the problems, both technical and institutional, present resource use, resources potential and resource use constraints associated with minor tank rehabilitation is needed.

7. Following the PI survey is the execution of a Full Investigation survey (FI survey) for the tank screened through the PI survey methodology. The FI survey includes: demarcation of catchment area using 1: 63,360 (1: 1 mile) topographic survey sheets of the Survey Department; tank bed contour survey; tank bund survey; survey of the command area to facilitate the design of irrigation canal layout; and assessment of the rehabilitation improvements. It is worth noting here that the ground contour intervals shown in the 1:63,360 topographic survey sheets is too large that the catchment area cannot be demarcated and evaluated accurately. Instead, the agricultural base maps having 1:10,000 scale and 5 ft contour intervals will have to be used for this purpose in the future.

8. Based on the FI survey, the technical officer is expected to produce a hydrological and technical design for rehabilitation. It is noted here that the designs and construction drawings prepared for rehabilitation needs improvements in quality, accuracy and completeness. Although, the project report is usually the basis for undertaking or rejecting the candidate tank for rehabilitation, it also

needs improvements in coverage, and accuracy of baseline information used for project appraisal.

9. Review of literature on rehabilitation projects previously conducted in the North Central Province reveals that the selection criteria hitherto used by the previous rehabilitation projects have not paid adequate attention on the overall hydrology of tank cascades. The studies reveal that individual tanks were selected for rehabilitation and restoration without understanding the overall position and their hydrological and socio-economic inter-relationships of tanks in the tank cascades or watersheds of the NCP. **Tank selection criteria were not framed to take into account the watershed concept. Also, no emphasis was given to assess the hydrological potential of individual tank cascades. A notable and important point is that the indicator 'cropping intensity', which integrates both the land and water resources use of tank cascades as well as individual tanks, was not considered as a criterion for tank selection.**

10. Also, at individual tank level too, assessment of hydrology, irrigation potential of the tanks, cropping intensities, cropping patterns and organizational aspects were not studied in greater detail. Many aspects that influence hydrology of a tank such as the land use in tank catchment, deterioration of land cover in catchments that causes siltation of tank, tank bed cultivation by encroachers, clogging up of natural drainage ways in the catchment due to road construction and human settlement, use of ground water by dug-wells in catchment, highlands and command area are not studied at all. At present, use of ground water as a source of supplementary irrigation for non-rice crops (NRCs) is becoming inevitable to increase cropping intensity in the NCP. **A proper assessment of groundwater availability, ground water recharge, present abstraction rates, available groundwater potential and possibility for providing or preventing more dug wells in the catchment or command, is not carried out at present. Also socio-economic aspects that affect proper water management in the command such as farmer organizations, dispersion and fragmentation of lands in 'puranawelas' (old paddy tracts), interactions between rain-fed chena cultivation and irrigated paddy cultivation in maha season, and production constraints such as lack of credit, extension, seeds, farm power and marketing are also not studied during the FI survey.**

11. It is noted that organizing farmers and forming farmers' organizations have become a major intervention in minor tank rehabilitation in the ongoing rehabilitation programmes, particularly, with the NIRP. However, a proper assessment of land and water resources potential and use in the tank based village and potential for resource user organization in improving the production and income is not done. Therefore, the PI and FI survey procedures as well as selection criteria for minor tank rehabilitation need to be modified and a more rational approach be adopted.

12. The rapid field appraisal survey and the literature survey indicated that the expectations of rehabilitation have not been fully realized in the 10 tanks studied. Cropping intensities have remained unchanged or rather declined in some instances, additional extent have not been cultivated, farmer incomes have not increased after rehabilitation. On the other hand, frequency of spilling of tanks have remained as low as only twice during the past 10 years, and on the average, tanks have filled only to its less than 75% full storage during the previous 10 maha seasons. Many tanks spilled only in 1983 and 1993 maha seasons, which brought exceptionally higher rainfall to the NCP and other parts of the country. **Table 1** highlights this situation.

13. However, the frequency of tank spilling and tank filling does not imply that there is no or little hydrological and human interactions between individual tanks of a cascade. Low frequency of tank spilling and tank filling may have resulted from restoring tanks in the cascade which had been previously abandoned and non-working or from raising tank bund to improve the capacity of some tanks in the cascade form time to time, without understanding and considering the overall hydrology of the cascade. On the other hand, even though the tanks do not spill or fill to its full capacity, there are significant hydrological interactions between the tanks. For an instance, the in a normal rainfall year, even though each individual tank of the cascade do not spill, the drainage return flows to a tank from lowland rice cultivated area of the upstream tank is a significant component of the tank water balance. On the other hand, in years of excess rainfall, when the tanks begin spilling, the safety of each individual tank and crops grown under the tanks of a tank cascade depends on careful operation of the entire cascade.

14. In view of this situation, a review of the hydrological design parameters was carried out as a part of this consultancy. This study compares the 75% probability rainfall values which are presently used by the national agencies for tank rehabilitation design and operation studies, with 75% probability monthly rainfall values computed on the basis of long term daily rainfall data at 14 meteorological stations that represent the NCP. The evaluation shows that the present values underestimate the rainfall potential for the tanks in the North-eastern part of the NCP and overestimate for tanks elsewhere. The hydrological analysis compares the catchment runoff coefficients presently in use with values deduced by a number of minor tank water balance research studies conducted in the NCP. Comparison of catchment runoff computed by different catchment run-off models, including the one presently in use, with the spilling and filling history of the 10 tanks studies during the rapid field appraisal survey shows considerable differences. The need to consider drainage return flows generating from the paddy cultivated area of upstream tanks in the cascade and direct rainfall

Table 1.

COMPARISON OF REHABILITATION DESIGN ASSUMPTIONS AND ACTUAL PERFORMANCE

NAME OF TANK	CATCH. AREA (Sqmls)	FULL STORAGE (Acft)	COMMAND AREA (Reported) (Acres)	COMMAND AREA (Actual) (Acres)	CATCH. STORAGE RATIO (acres/acft)	CATCH. STORAGE RATIO (ha/ha.m)	CATCH. COMMAND RATIO	STORAGE COMMAND RATIO (Acft/Ac)	SPILLING INDEX	FILLING INDEX(F) (100%<F >75%)	FILLING INDEX(F) (75%<F >50%)	FILLING INDEX(F) (F<50%)	CROPPING INTENSITY (Maha)
Hiriwadunna	4.00	536	135	110	4.78	15.67	23.27	4.87	1.0	0.0	0.0	0.0	0.67
Punchikulama	1.60	445	180	110	2.30	7.55	9.31	4.05	0.2	0.1	0.3	0.4	0.13
Sivalakulama	0.92	492	145	135	1.20	3.93	4.36	3.64	0.2	0.3	0.5	0.0	0.3
Maradankadawala	1.59	244	162	100	4.17	13.68	10.18	2.44	0.4	0.3	0.3	0.0	0.3
Paluketuwewa	1.00	590	190	190	1.08	3.56	3.37	3.11	0.3	0.2	0.2	0.5	0.34
Bellankadawala	2.80	620	115	115	2.89	9.48	15.58	5.39	0.4	0.3	0.3	0.0	0.96
Kiriibewa	0.80	302	100	103	1.70	5.56	4.97	2.93	0.2	0.8	0.0	0.0	0.73
Nelugollakada	1.88	315	148	148	3.82	12.53	8.13	2.13	0.8	0.2	0.0	0.0	0.63
Elapathgama	0.80	–	87	87	–	0.00	5.89	0.00	0.1	0.0	0.0	0.9	0
Anduketiyawa	0.60	152	123	62	2.53	8.29	6.19	2.45	0.2	0.8	0.0	0.0	0.71
Vendarankulam	0.75	178	45	45	2.69	8.82	10.67	3.95	0.5	0.2	0.2	0.1	0.72
Bulankulama	0.25	81	45	42	1.97	6.46	3.80	1.93	0.5	0.5	0.0	0.0	0.75
Meegassagama	1.37	292	80	80	3.00	9.84	10.96	3.65	1.0	0.0	0.0	0.0	0.75
Alisthana	1.43	470	96	96	1.94	6.36	9.53	4.90	0.4	0.6	0.0	0.0	0.80
Thirappane	1.73	640	85	85	1.73	5.67	13.03	7.53	0.2	0.8	0.0	0.0	1.00

falling to a tank during yala and maha season in carrying out tank operation studies are noted.

15. This implies that: hydrological parameters presently in use for estimating catchment runoff such as design rainfall values, catchment runoff coefficients; and other tank inflow and outflow parameters such as drainage return flow percentage from paddy areas of upstream tanks in the cascade, direct rainfall percentage falling to tank water spread area during the season etc; are in need of rational refinement. It is also required to consider operational aspects of irrigated agriculture in tank cascades and under individual tanks in selection and design of tanks for rehabilitation. For example, the farmers in the NCP rarely commences land preparation for paddy in the maha season with the onset of maha seasonal rains. Instead, they attend to chena cultivation first and return to the irrigated command only after preparing land and sowing crops in the chena. Thus, the use of early rainfall for land preparation in maha is at levels less than desired. A computer model that can simulate those different operational and hydrologic conditions for minor tanks is developed under this consultancy. This model was used with data and information gathered during the field appraisals in respect of a number of minor tanks to compare the actual performance of the tanks with the simulated conditions and recognize the actual hydrologic and operational scenarios prevailed. The simulation model was used as a tool and a guide to evaluate the hydrologic design parameters that are most appropriate for the NCP.

16. Also, our studies imply that physical tank rehabilitation and organizing farmers alone will not bring the expected post-rehabilitation benefits to farmers. Instead, a rational rehabilitation approach, which considers the resources base of a minor tank environment as the focus of attention and an approach which considers physical tank rehabilitation only as a single component of a package of development interventions for the tank based village need to be adopted. Also, in adopting this rural development approach which may enunciate minor tank rehabilitation as a necessary but not a sufficient intervention for rural development, the overall water resources availability, cropping intensity and irrigation potential of the entire cascade will have to be adequately considered.

3. THE NEED FOR A DIFFERENT APPROACH FOR TANK SELECTION FOR REHABILITATION

The tank rehabilitation approach proposed by this consultancy is different to the approaches that have been adopted hitherto. It primarily considers tank rehabilitation in the context of land and water resources management within a given watershed unit. In the NCP, tank cascade is the basic watershed unit considered for integrated land and water resources management. It discourages the piece-meal approach of selecting tanks for rehabilitation without paying adequate attention to the overall hydrology and potential for irrigated agriculture of the cascade. It also discourages the water resources development component of the proposed Integrated Rural Development Project funded by IFAD, being considered and implemented as a separate intervention divorced from land resources management component of the project. Instead, it promotes an integrated rural development approach based on cascades at the first level and based on tank watersheds at the next level. The new approach stresses the need for the catchment, tank, highlands, command and drainage area of a tank in the NCP being considered the mosaics of a geographically and socially integrated, micro-watershed unit for integrated rural development planning and implementation, under which tank rehabilitation may be considered and implemented for proper management of land and water resources within that watershed unit in order to improve the income and well-being of the people. In essence, tank rehabilitation is identified not only in the context of irrigation management but also in the broad context of land and water resources management.

The need for developing a more acceptable criteria for selecting and promoting tanks for rehabilitation emanates from the need for adopting a more sensible approach for land and water resources management in the NCP as described above. The approach and guidance package suggested by this consultancy attempts to ensure a more acceptable strategy for land and water resources management in the NCP.

The overall approach suggested for tank selection for rehabilitation, which is self-explanatory, is illustrated as a flow diagram below.

4. A FRAMEWORK FOR MINOR TANK SELECTION FOR REHABILITATION

Conduct a participatory rapid appraisal survey of land and water use identifying particularly CI of various tanks under a chosen cascade

↓

Characterize the tank cascade system based on topography, soil, geology, hydrology and land use with regard to potential for further development

↓

Characterize individual tank in a cascade for its potential for rehabilitation (Hydrologic potential, technical potential and managerial potential).

↓

Analyze surface water potential of individual tank under cascade for improving CI through Hydrologic Simulation model.

↓

Analyze groundwater situation of the sub-watershed and estimate the potential for agrowell development.

↓

Carry out a technical survey and analysis for individual tanks to improve the physical aspects of tank inflow, tank storage capacity, tank water distribution.

↓

Conduct a SWOT analysis to identify management interventions to be introduced.

↓

Carry out a benefit-cost analysis to prioritize tanks for tank rehabilitation.

↓

Based on B-C ratio, pro-rata cost and EIRR select tank for rehabilitation.

↓

Carry out detailed design for tank rehabilitation.

5. THE GUIDELINES

Annexure 1 of this report presents the general characteristics of tank cascades in the NCP with particular reference to Anuradhapura district. It also provides an explanatory text and rationale for the selection of the five particular cascades of this study. The characterization that follows in **Annexure 1** and below is based on a detailed study and examination of the distribution pattern of those five small tank cascade system (STCs) of the Anuradhapura district from the 1 inch to 1 mile (1:63,360) topo-sheets, supported by a detailed field study of five selected representative STCs.

5.1 Characterizing a Tank Cascade System

5.1.1 The following approach was adopted for characterizing a STCs in this environment. A three level characterization is proposed as follows:

Level 1.

Typology — which gives the broad layout and disposition of the valleys and small tanks within the cascade or the micro-catchment.

- three typologies are proposed, namely:

  (1) Linear type cascade;
  (2) Branched type cascade; and
  (3) Transitional type cascade.

Level 2.

Descriptors — which gives a description and figurative characteristics of the STC. These include:

- size, length and breadth of the micro-watershed (catchment); and

- location of side valleys with respect to the main valley and its axis.

Level 3.

Determinants — which is a measurable parameter that governs the hydrological character of an STC,

- the two main determinants recognized are:

  (1) land form of the micro-catchment and its surroundings; and

  (2) slope class of the axis of the main valley.

5.1.2 Logical steps to be followed in characterizing a cascade is as follows:

Step 1: On the 1 inch to 1 mile topo sheet demarcate the main watershed boundary of the meso-catchment basin within which the total cascade is located. This could be done visually on the standard 1 inch topo sheet.

Step 2: Transfer the above to the presently available 1:50,000 Survey Department Agricultural Base Maps printed in 1985 and based on 1982 air-photographs. Next demarcate the micro-catchment boundaries for each individual tank within the cascade. This will thus provide a composite picture of the shape and form of the cascade.

Step 3: The first step in characterization, namely the typology, ie. linear, branched or transitional can be made at this stage.

Step 4: Enlarge the 1:50,000 scale map with all essential details shown on it to 1:25,000 scale (double enlargement). Using this as the field sheet, field check accuracy of the meso- and micro-catchment boundaries. Also demarcate the following: (a) location and area of tanks and waterspread, (b) paddy command area, (c) homestead settlement area, (d) chena area, (e) scrub land, (f) forest, and (g) rock outcrops.

Step 5: Using a set of standard descriptors describe the cascade in terms of its size, length, breadth, alignment, uniformity, and location and number of side valleys and smaller tanks within the side valleys.

Step 6: At this stage assess the determinants as follows:

(i) Examine the land form of the meso-catchment and its surroundings with the aid of the available air-photographs and rapid field study. Characterize the land form in terms of a) undulating or, b) gently undulating. Also describe the sub-determinants such as the catchment/tank area (C/T) ratio, location of tanks in valley confluence, and presence of rock outcrops.

(ii) Estimate the slope class of the axis of the main valley.

Step 7: This completes the characterization of the cascade in terms of its typology, descriptors and determinants. Product is a map and supporting table, which characterizes the cascade in meaningful terms.

5.1.3 Evaluating the Potential of the Cascade

<u>Step 8:</u> Traverse the cascade, preferably from top (head-end) to the bottom (tail-end) studying the main features of each tank within the cascade. Note the following information for each tank.

(a) cropping intensity during <u>maha</u> season for the past five years,

(b) the tank locations within the cascade, i.e. whether at top, middle or bottom; or at the confluence of two side valleys with the main valley axis.

(c) ratio of micro-watershed area to tank spread area, and special features such as rock outcrops, rock-knob planes (RKP), erosional remnants and quartizitic ridges, etc.

(d) General information as to why the full command area does not get cultivated during a season of very good maha rainfall with full tank supply - whether it is technical or socio-economic.

The above set of information (a) to (d) taken together will provide a preliminary evaluation of each tank behavior as well as the reasons as to why particular tanks within the cascade are not achieving their real potential.

<u>Step 9:</u> Obtain the weighted means of the cropping intensity (CI) for each <u>cascade</u>. This weighted mean will be based on the lowland paddy area of each tank within the cascade. The well endowed cascades will have a higher weighted mean CI than the less well endowed ones.

<u>Step 10:</u> Finally rank the cascades in terms of their weighted mean scoring.

5.2 Selection of Tank Cascades for Further Analysis

During the evaluation **Step 8** (a-d) one could get a better understanding of the gap between the potential and the present performance of any particular tank within the cascade, and also the potential for further improvement of the performance of the cascade as a whole in terms of its weighted mean cropping intensity.

Apart from the lowland irrigated small tank component, one should also take into consideration other significant opportunities that occur within the cascade for open dug-well (agrowell) cultivation, and also further stabilization of chena cultivation on good quality highland.

Adopt the following steps in the selection of tank cascades for further analysis.

Step 1: Make the following three broad groupings of cascades based on the weighted mean average of cropping intensity for the maha season.

(a) more than 75 percent,
(b) between 60 to 70 percent,
(c) less than 60 percent.

Step 2: First select those cascades that have a weighted mean CI of less than 60 percent and examine the contributory causes, namely whether it is brought down by a certain number of non- or poorly functioning small tanks within the cascade; or whether the cascade is poorly endowed in terms of its overall land form type and catchment size and/or lower rainfall regime. Also examine the potential for dugwells within the cascade that could enhance its cropping potential. In keeping with the poverty alleviating goals of the proposed NCP Rural Development Project this category of cascades should receive a higher priority in the selection process.

Step 3: Next select those cascades that have a weighted mean CI of between 60 to 75 percent. Examine the reasons for the lower weighted mean CI, whether it is because of the mal-functioning of the larger size tanks in the central valley of the cascade or other causes such as land tenure problems in 'puranawela'. As in **Step 2**, also examine the potential for open dugwells within the cascade.

This category of cascade should receive the second priority in the selection process.

Step 4: Next select those cascades that have a weighted mean CI of more than 75 percent, and make a field appraisal to find out whether any further improvements would be technically feasible or justifiable. If it would involve only a small low cost rectification that would enhance the CI value of the cascade then it could be considered favorably.

This category of cascade will receive a lower priority than the other two in the overall selection process.

It could also be useful at a later stage to analyze the causes for the gap between potential and present performance of the individual tanks especially the larger ones with more than 500 acres of water-spread area. Results from such an analysis would help in the future to refine the selection process of cascades for rehabilitation.

5.3 Surface Water Estimation, Selection and Design of Tanks for Rehabilitation

Chapter 2 of this guidance package highlighted some shortcomings of the present process of tank selection and design for rehabilitation and the need for developing a rational approach for tank selection. It is also required to have a rational basis for determining the nature of rehabilitation and the intensity of financial investments that should be set apart for a given tank contesting for rehabilitation. Chapter 2 also emphasized the need for refining the present rehabilitation design parameters too. This section presents an approach, indicators and criteria for tank selection for rehabilitation and hydrological parameters recommended for rehabilitation design. The basis for the proposed approach for tank selection and hydrological design parameters are elaborated in **Annexures 2 and 3** respectively.

The process of surface water estimation, tank selection and design for rehabilitation can be considered as a four stage approach consisting of:

Stage 1 - Preliminary study
Stage 2 - Detailed study and analysis
Stage 3 - Tank selection for rehabilitation
Stage 4 - Tank rehabilitation design

The sequential steps of implementation for each of the above stages are elaborated below.

Stage 1: Preliminary Study

Step 1: A tank based village, which is usually a 'sub-watershed' of a larger cascade, is proposed for area development under the Integrated Rural Development Project, based on the requests originated from an interest group. Also, there would be requests from various interest groups for rehabilitating tanks. Consider that tank for further analysis.

Step 2: A multi-disciplinary team operating at local level carries out a participatory rapid appraisal survey and mapping of the sub-watershed following the approach and methodology suggested in **Annexure 10**. The survey would focus on the evaluation of the present use and status of land and water resources, their present productivity levels, production constraints and opportunities, ways and means of alleviating those constraints to increase the sustainability of the resources base, productivity as well as income to the inhabitants. These information will be made use in our analysis for further information collection, if necessary.

Step 3: Collection of basic data and information required for a preliminary assessment of the physical and hydrological parameters of the tank in the village too is carried out during this study. The data that should be essentially collected are: catchment area; catchment land use pattern; tank water depth; approximate water spread area of the tank at full supply; command area; and the cropping intensity at least during the previous 5 maha seasons. It is preferred to use 1:10,000 maps with 5 ft contour intervals to compute the catchment area and to delineate other field details.

Stage 2: Detailed Study and Analysis

The Detailed study and analysis is meant for selecting an individual tank for rehabilitation, and for determining the nature of rehabilitation and level of financial investments set apart for rehabilitation improvements.

The criteria for selecting a tank for rehabilitation, identifying appropriate rehabilitation strategies, and level of investment is suggested below. The criteria are based on three key indicators namely, Maha Cropping Intensity (CI), ratio between Tank Catchment Area (CAA) and tank Water Spread Area (WA) [CAA/WA], and ratio between Command Area (COA) and Water Spread Area (WA) [COA/WA]. The basis for developing the indicators and the criteria are described in **Annexure 2.**

The step-wise procedure for appraising an individual tank for rehabilitation is as follows.

Step 4: Compute the ratios CAA/WA and COA/WA. For a tank having good hydrology the CAA/WA ratio should be over and above 7.5 and COA/WA ratio be less than 1. A tank having an adequate capacity to feed its command area should have COA/WA ratio less than 1. For details refer to **Annexure 2.**

Step 5: The maha CI should be the basic parameter for tank selection for rehabilitation. Four ranges of CI is considered in this analysis. Those are : i) very close to 1.0; ii) between 0.85 and 1.0; iii) between 0.60 to 0.85; and iv) less than 0.60.

Step 6: Any tank considered for rehabilitation should be considered under one of the categories as given below.

Category A:

Tanks which have CI of almost 1.0 and have little hydrologic potential for expanding its command area (i.e. CAA/WA ratio is much less than 7.5). No improvements, other than essential urgent repairs required (ex. to ensure the safety of the tank), are considered necessary.

Category B:

Tanks which have CI anywhere between 0.85 and 1.0 and have hydrologic potential for expanding its command area (i.e. CAA/WA ratio is higher than 7.5. If COA/WA ratio too is less than 1.0, they have excess tank capacity to undertake more command area. Such tanks should be considered for capacity improvements, technical and managerial improvements to expand the command area, if required and feasible.

Category C:

Tanks which have CI greater than 0.60, but less than 0.85, and have adequate hydrologic potential and tank capacity to increase the cropping intensity (i.e. CAA/WA is greater than 7.5 and COA/WA is less than 1.0). They have adequate hydrologic potential and adequate tank capacity to feed the existing command area. Hence, the low CI may be due to technical and managerial deficiency and cannot be due to deficient catchment yield potential or tank storage capacity. Such tanks should be considered only for managerial and technical improvements.

Category D:

Tanks which have CI much less than 0.60 and have inadequate hydrologic potential, (i.e. CAA/WA is less than 7.5). No technical improvements can increase the CI significantly due to low hydrologic potential. Such tanks should be considered for agrowell development and low-cost managerial improvements.

The following section elaborates: the basis for the above characterization; nature of rehabilitation work for each category; identification of the category to which the tank under consideration fall into; the intensity of financial investment for each of the above category; and criteria for selection for rehabilitation. Indicative pro-rata levels of financial investments for each category are proposed at the end of this section.

Step 7: If, CI = 1.0 and CAA/WA is lower than 7.5, the tank has a little hydrological potential for further expanding its command area, although downstream lands are available for command area expansion. There is no necessity for selecting that tank for intensive rehabilitation, unless there is (are) some urgent repair (s) to be attended (ex; bund about to breach). If it is possible to undertake additional lands under command with low cost technical improvements, such as extending the existing irrigation canal or providing a few canal structures, only those requirements may be met after a quick field evaluation. No detail studies are required for such tanks. Tanks falling into this group are called Category A tanks.

Step 8: If, CI = 0.85 - 1.0 and CAA/WA is (much) higher than 7.5, the tank has a hydrological potential for expanding its command area, if its COA/WA ratio too is much lower than 1.0 and tank water depth at full supply is more than 7.5 feet.

Such tanks may be considered for command area expansion by raising the full supply level provided that:

(a) The tank capacity improvement will not affect the hydrology and CI for the downstream tanks of the cascade;

(b) The upstream paddy lands or settlement will not go under water due to the increasing of the full supply level; and

(c) Additional lands are available under the tank for development.

The simulation model described in Section 5.4 should be used to carry out trial runs to assess the influence of the proposed improvements on the hydrology of the cascade.

If the conditions a, b and c above are fulfilled, it should be considered for command area expansion. However, as a rule of thumb, the surface area of the tank after improvement should be such that the ratio CAA/WA is kept at the limiting value of 7.5 and the ratio COA/WA at 1.0. These limiting criteria provide a basis for determining the maximum allowable command area after expansion too (by using the criteria COA/WA = 1.0).

For tanks fulfilling the above conditions and criteria, detailed hydrological, technical, socio-economic and managerial analysis should be carried out as described in **Annexure 8**. The tanks falling into this group are called Category B tanks.

If any of the above conditions a, b and c are not fulfilled the tank should not be considered for command area expansion. In that case, tanks falling into this group too should be considered as Category A tanks.

Step 9: If, CI = 0.85 - 1.0 and CAA/WA is higher than 7.5, but COA/WA ratio is higher than 1.0 it would not be possible to expand the command area, although, the tank has a hydrological potential to do so. Such tanks should not be considered for command area expansion although additional downstream lands are available for cultivation. For those tanks there is no necessity for carrying out detailed studies. Tanks falling into this category too should be considered Category A tanks.

Step 10: If, CI = 0.60 - 0.85, CAA/WA ratio is higher than 7.5, COA/WA is less than 1, the tank should not be considered for increasing its capacity as the reason for lower CI may be not due to hydrological deficiency. However, for tanks whose CI is high, say, more than 0.85, it may mean that it has a good catchment yield and it is possible to improve the cropping intensity to 1 with: a) enhancing runoff to tank; or b) low cost management improvements; or c) technical improvements without raising its full supply level; or combination of one or more of the above three interventions. Again, the simulation model should be used to select the appropriate interventions. For such tanks only the technical, socio-economic and managerial analyses should be carried out. Tanks requiring both technical or managerial improvements or both are called Category C tanks.

Step 11: If, CI is low (<0.60), but CAA/WA ratio is higher than 7.5 and COA/WA ratio is much less than 1.0, the tanks may be considered for improving its capacity after evaluating its influence on the overall hydrology of the cascade. For such tanks, detailed hydrological, technical, socio-economic and managerial analysis are required. Those tanks would fall either to Category B or C. If there are constraints in increasing its capacity, as explained under step 8 above, it should be considered as a Category C tank.

Step 12: If,CI is low (< 0.60), and also CAA/WA ratio is much lower than 7.5, it is not worthwhile to invest on such tanks unless for low cost managerial improvements. Tanks falling into this group are called Category D tanks. It is for these tanks agrowell development should be explored.

Step 13: At this point, the specific category of the tank under consideration is known. A summary of the categorization is as follows.

CI	CAA/WA	COA/WA	Tank Category
1.0	< 7.5	> 1.0 or < 1.0	Category A
0.85 - 1.0	> 7.5	< 1.0	Category A or B
0.85 - 1.0	> 7.5	> 1.0	Category A
0.60 - 0.85	> 7.5	< 1.0	Category C
0.60 - 0.85	< 7.5	> 1.0 or < 1.0	Category C
< 0.60	> 7.5	< 1.0	Category B or C
< 0.65	< 7.5	> 1.0 or < 1.0	Category D

Step 14: Carry out a preliminary assessment of the quantum of rehabilitation work to be undertaken in a participatory manner and estimate the approximate cost of rehabilitation as is done now by the conventional Preliminary Investigation Survey (PI survey) carried out by the Irrigation Department. Based on the approximate cost of rehabilitation, compute the pro-rata cost of rehabilitation.

Step 15: Level of investments for different categories should be different. However, the final investment decision for integrated rural development should be based on the total package of interventions proposed for the tank based village, judged by a minimum level of Internal Rate of Return (IRR), and Cost-benefit (B/C) ratio. However, it will still be required to judge whether it is worthwhile for investing for rehabilitating a tank as a part and parcel of the total package for the tank-based village.

To make such judgements, the following criteria, based on pro-rata cost of rehabilitation is proposed.

Category	Pro-Rata Cost
A	Rs 20,000/ha
B	Rs 67,000/ha
C	Rs 50,000/ha
D	Rs 10,000/ha

Step 16: At this preliminary stage, if the pro-rata cost of rehabilitation is within the above limits for the tank under consideration, proceed with further hydrological, technical and managerial analyses and studies required as indicted in **Annexure 8.**

Stage 3: Tanks Selection for Rehabilitation

The above analysis illustrate how an individual tank is analyzed for its potential for rehabilitation. The criteria for tank selection for rehabilitation expounded in this report are based on the following assumptions. It is recommended that the guidelines given below should be followed in the selection process.

(1) Most of the tanks in the dry zone exists as cascades. The several tanks within the cascade are dependent among themselves in nature as far as the hydrology and water resources are concerned. In view of this, the basic unit to be considered first is the total tank cascade rather than the individual tank for analysis. It is essential to look at the performance of the whole tank cascade as a unit in terms of irrigation performance expressed by cropping intensity.

(2) Once a tank cascade is selected for rehabilitation, then further analysis is carried out to identify individual tanks, again based on cropping intensity. The procedure for this analysis was elaborated under Stages 1 and 2 above of this section. The individual tanks are then subjected to constraint analysis relating to water resources, technical deficiencies, managerial and socio-economic constraints. A set of questionnaires and a note on improving agronomic practices are presented in **Annexure 8**. Based on the analysis, potential interventions are identified, prioritized and ranked.

(3) The average CI existing under a tank command during the last five maha seasons is the basic parameter, or the dependent variable, which best determines whether a tank is to be selected for rehabilitation or not.

The CI of a tank integrates both the land and water resources of the tank, and technical, managerial and socio-economic constraints of the tank and its stakeholders. Therefore, it lends itself as an ideal indicator for tank selection.

(4) The parameters CAA/WA and COA/WA ratios, which are independent variables, can be used together with the CI to characterize tanks and identify the nature of rehabilitation that will have to be undertaken. Tank characterization in terms of its, agricultural performance (CI), hydrological potential (CAA/WA), adequacy of tank capacity (COA/WA) is a convenient basis for identifying its potential and nature for rehabilitation.

(5) The pro-rata cost of rehabilitation, Benefit-Cost ratio (B-C ratio) and Internal Rate and Rate of Return (IRR) are the three parameters which are ultimately used for selecting a candidate site for minor tank rehabilitation.

(6) The guidelines provided in the previous sections provide a step by step procedure to carry out an analysis and lead into selection of viable candidate site for rehabilitation. Rehabilitation is defined herein includes both 'hardware' and 'software' solutions. The hardware solution includes both physical rehabilitation and resource augmentation including use of groundwater through agrowells. The 'software' solution includes 'institutional', 'managerial' and 'organizational'. Each one of these components either singly or in combination with form the intervention.

(7) In addition, STRENGTH, WEAKNESSES, OPPORTUNITIES AND THREATS (SWOT) frame work should be used to do a comprehensive analysis of the existing environment. It will provide dual opportunities, i.e. appropriate criteria as well as indicators to planners for tank selection and provide a basis for project implementors for formulation of rehabilitation strategies. A comprehensive diagnosis of strengths and weaknesses of the existing environment of the tank would provide a basis for identifying the future opportunities and threat. The four aspects of analysis mentioned above would provide both planners and implementors with the opportunity to select suitable tanks and develop appropriate strategies for rehabilitation. A brief outline of SWOT framework and analysis for planning and a hypothetical case study of SWOT framework application is presented in **Annexure 9.**

Stage 4: Tank Rehabilitation Design

Tank rehabilitation design consists of three main parts. i.e. i) hydrological design, ii) technical design, and iii) managerial design. For Category B tanks all three design components should be carried out. For Category C both technical and managerial design need to be carried out.

None of the above design components are required for Category A and D tanks, except when essential/urgent repairs are undertaken.

This section deals only with the key considerations of the hydrological design as the terms of reference of this study is limited only to it.

Hydrological Design

Step 17: Prepare a cost estimate for carrying out a tank bed survey, command area survey (engineering survey) following the standard survey requirements and specifications of the Irrigation Department. It is presumed here that a land use survey details of the tank cascade is available at this point.

Step 18: Prepare a tank bed contour plan and develop tank water depth - water spread area - capacity relationship. Verify the CAA/WA and COA/WA ratios used for the detailed analysis using the water depth - area - capacity data and justify the possibility for expanding the command area by increasing the tank capacity using the criteria explained under Stage 2 above.

Step 19: The next step is to carry out an operation study to evaluate the probable command area under the tank using the simulation model. The input parameters, model variables, structure, and the advantages of the proposed simulation model is given in **Annexures 4 and 5**. The following guidelines with respect to the hydrological parameters should be used for developing the simulation model and tank rehabilitation. These guidelines are proposed based on the detailed hydrological analysis conducted for this study, which will be submitted with the final report. It is recommended that these guidelines be followed for the hydrological analysis of a tank.

Guidelines

The following guidelines are recommended for planning, design and operation of minor tanks. These guidelines have been developed on the basis of the detailed hydrological analysis carried out for this consultancy. A summary review of the findings of the hydrological analysis are given in **Annexure 3.**

Rainfall Analysis

(a) The use of a single set of 75% probability rainfall values for the design of tanks in the entire NCP may lead either to the underestimation or overestimation of the available catchment yield. Thus if the 75% rainfall values for the DLI region are used for a tank in the NE part, the rainfall is underestimated by 28% and if used for the SW part, the rainfall is overestimated by 13%. Therefore, it is recommended to use the 75% probability rainfall values of the closest rain gauge station when a tank is considered for rehabilitation. Standard methods such as Theisson's Polygon Method may be used to divide the NCP to different design rainfall regions for this purpose.

Iso-yield approach

(b) At present, catchment yield is estimated using the iso-yield approach, (Ponrajah, 1988). Instead of following the entire computational procedure, one may simply apply a runoff coefficient of 0.35 to 75% probability rainfall values to obtain catchment runoff in maha season. What is required is only to check whether the first value of iso-yield read from the map is less than 410 acft/sq mls.

Catchment runoff coefficients

(c) The catchment yield, computed on the basis of runoff coefficients deduced by a number of minor tank water balance studies conducted in the NCP, differ from the catchment yield computed on the basis of iso-yield approach using 75% probability rainfall for DL 1 agroecological region. The latter gives higher values than all of the other models. In view of the above situation, it is essential to select the most acceptable catchment runoff estimation model. It is not possible to recommend one single model for this purpose at this point of time as no adequate research information is available to arrive at conclusive values. Therefore, it is recommended that a runoff coefficient of 0.30, instead of 0.35 be used to 75% probability rainfall of the closest station reduced by a pre-saturation requirement of 200 mm, until more conclusive data would be available in the future.

Drainage return flow and direct rainfall

(d) The contribution by drainage return flow from the upstream areas cultivated and direct rainfall falling to tank bed during the season are not taken into consideration for tank water balance studies at present. Thus, those two parameters should be considered. Simulation studies show that the probable command area of a tank increases by about 16% when both direct rainfall and drainage return flows are taken into account. Thus, both these parameters should be evaluated and considered in hydrological design and operation studies as water inputs to tank. A drainage return flow coefficient of 0.2 should be used for this purpose.

5.4 Simulation Modelling of Tank Cascades and Individual Tanks

Once a tank cascade is selected for further analysis based on maha cropping intensity (CI) and other parameters explained in Section 5.3 of this report, the next step is to evaluate the potential CI of each tank of the cascade.

The actual or realized CI of a tank or tanks of a cascade in maha season is the basis for characterizing individual tanks and finally the hydrological potential of the tank cascade. It is used together with parameters (ex. CCA/WA and COA/WA ratios) to characterize individual tanks and to identify the nature of rehabilitation work that should be undertaken. For this purpose, a tank simulation model is developed, the details of which is given in **Annexure 4.** The operation manual of the computer model called 'Reservoir Operation Simulation Extended (ROSE Version 2.0) System is in **Annexure 5.** This model will be used for evaluating a tank for rehabilitation.

The primary model inputs are (references shown in parentheses against each input parameter):

- catchment area of the tank (Chapter 2, Section 7);
- monthly 75 % probability rainfall values and catchment run-of coefficients (Section 5.3 and **Annexure 3**);
- monthly open water evaporation rates and tank loss rates (Ponrajah, 1985, unless site specific data are available); and
- Direct rainfall to tank and drainage return flows from upstream lowland rice cultivated areas during a cultivation season (Section 5.3 and **Annexure 3**).

The variable input parameters are:

- depth-area-capacity relationship of the tank;
- assumed cropping pattern;
- respective areas of well-drained and poorly drained soils of the yank command area;
- assumed date of commencement of the season (land preparation);
- assumed/actual conveyance efficiency of the canals; and
- assumed/actual farm application efficiencies.

These variable inputs may be quantified forms of various physical, managerial, technical and organizational improvements contemplated or simulated under the rehabilitation package. The model can be run for different combinations of variable inputs to simulate Cropping Intensity (CI) or probable command area for each combination of variable input parameters representing various physical, managerial and organizational interventions contemplated.

5.5 Groundwater Estimation and Agrowell Development Under Each Tank in a Tank Cascade

A review of the available literature on geology, hydrogeology, and groundwater conditions of the NCP was carried out for this consultancy. Based on the review, a summary on 'An Analysis of Groundwater Resources, its Estimation and Abstraction Through Agrowells in Anurdhapura District' is presented in **Annexure 6**. The guidelines that follow are based on this review.

The following are the steps involved in groundwater estimation in a cascade system:

Step 1: Prepare a detailed land use map of the micro-watershed (cascade system) indicating the catchment area contributing to the tank, tank water-spread, lowlands paddy area, upland chena, scrub and homestead (settlement, recent chena, old chena) area, and upland area contributing to drainage through paddy land. It is essential to use 1:10,000 maps with 5 ft contours to delineate these areas more carefully and then field check the map prepared.

Step 2: Find out the area of each of the above category of land including tank storage.[3]

Step 3: Identify the hydrogeological condition of the micro-catchment such as weathered overburden, number of agrowells, number of drinking water supply wells, groundwater level fluctuation, etc. This can be obtained from participatory resource mapping techniques.

Step 4: Estimate the recharge rate from catchment area, tank water spread area and paddy irrigated area[4].

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[3] Use the thumb rule V = 0.4 x A x D, where V is the tank storage, A is the waterspread area assessed from topo or 1:10,000 maps and D is the average full supply depth at sluice head.

[4] The average recharge in the catchment area of the dry zone has been worked out by a number of investigators as 110 mm/year. Of this, 50 percent would be allowed for maintaining flora and fauna of the catchment and for base flow, and the remaining 50 percent is available for extraction through wells.

The average recharge under the tank waterspread is equal to 160 mm which is governed by the weathered formation and not the water availability.

For paddy irrigated land, the recharge rate is equal to groundwater level fluctuations multiplied by the specific yield, (i.e if 7.5 m is the groundwater level fluctuation then the recharge in irrigated paddy area = 7.5 x 20 = 150 mm, where 20 mm is specific yield/meter.

Step 5: Estimate the recharge contributed by the catchment area, tank waterspread area and paddy irrigated area. The sum of all these three components gives the total estimates of groundwater available for extraction.

Step 6: Find out the present groundwater used by:

(a) Tube and domestic wells for drinking water supply,
(b) Agrowells.

The drinking water supply as per COWI Consultants (see reference) works out to 1 mm/ha of micro-watershed.

Estimate the groundwater extraction from an agrowell in the upland area which uses groundwater both during maha and yala seasons and an agrowell situated in the low-lying paddy area which abstracts groundwater only during the yala season.[5]

The present use of groundwater can be evaluated by knowing the number of agrowells in the upland area and multiplying by 7000 and the number of agrowells in the low-lying paddy land multiplied by 3000.

Step 7: The difference between quantity of groundwater estimated under **Step (5)** and **Step (6)** gives the groundwater available for further extraction.

Step 8: Determine the number of additional agrowells that can be constructed within the micro-watershed taking into consideration the irrigable area available both in the upland and in the low-lying paddy land.

Step 9: **Siting of Agrowells**

Hard rock aquifers encountered in NCP are low transmissivity aquifers, capable of holding groundwater only in secondary porosities created by weathering, valley fills, faulting and jointing. Only wells constructed in these locations are capable of yielding sufficient quantity of water for agricultural purposes. Therefore, in hard rock aquifers, wells cannot be constructed in any place without looking into the hydrogeology of that area. **In other words, delineating the probable area**

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[5] A method is indicated in the Final Report to compute groundwater extraction from an agrowell based on the crop and the areal extent irrigated. By this method, it is estimated that an agro-well in the upland area would use 7000 m^3 of water per well while that in the low-lying paddy land would use only 3000 m^3 of water per agro-well. This is because upland agro-well uses water both during maha and yala seasons while agro-well in the lowlying paddy land uses well water only during the yala season.

for well construction in a micro-watershed is a pre-requisite for successful construction and use of agrowells

A number of methods such as geophysical, geological, air-photo analysis and drilling are available to identify potential zones for agrowell construction. One or more of these methods need to be used to identify these potential zones.

In addition, the following general criteria can be followed while selecting sites for agrowells:

(a) The terrain selected for agrowell construction should be flat or gently sloping and will not exceed in slope more than 5°,

(b) Some of the most suitable locations are:

- downstream of existing or abandoned tanks,
- valley fills or valley axis,
- downstream of rock outcrops having considerable recharge potential,
- areas where plant life indicates a high water table,
- along drainage valleys.

Having selected a site within this delineated zone, one can further confirm its suitability by constructing a pilot well of 1.2 m diameter to a depth of about 5 to 7 m and testing it for recuperative capacity by completely pumping out the well water. A recuperation of 100 mm in the first hour after pumping stopped is considered sufficient for providing adequate water during dry weather period. Such a site is considered a suitable for agrowell development.

Step 10: **Selection of Agrowell Owners**

(i) From the technical point of view, the owners of the agrowells should be situated in and near the zones delineated for agrowell development. Too much distance from the centre of agrowell development will increase the cost of distribution system.

(ii) From among the farmers who are located nearer the zone of groundwater availability, preference be given to:

- those who do not own paddy land,
- those whose annual income is less than a prescribed minimum,

- those who have sufficient family labor, willing to take up OFC cultivation and credit worthy, etc.

(iii) The selection of farmers for owning agrowells as well as monitoring and regulation of agrowells within a micro-catchment should be left to the villagers or a committee constituted at the village level to take care of agrowell development; this committee at the village level should be aware of the locations where agrowells can be constructed, the probable number of agrowells that can be constructed in the upland and low-lying paddy land so that they can monitor and regulate the development of agrowells within their micro-catchment.

The Technical Expert Team should work with this committee and provide necessary training and support to carry out their task effectively.

Step 11: **Management of Agrowells Within a Micro-Catchment**

For sustainable agrowell development and use, the total extraction of groundwater from the micro-watershed should not exceed the potential extractable recharge (safe yield of the aquifer). This then requires the complete cooperation of the beneficiaries using the agrowells. To get their full cooperation and to use the agrowells more efficiently, it is suggested that the farmers owning agrowells at a village level be brought as a group for providing training, information dissemination and other support services including repair of pumps, etc; and they be also federated at the cascade level. Such a group will act as a stakeholder for sustaining the agrowell development program within the cascade and at the same time arrange for training, repair and other support services that can be provided through this federated organization. Again, the Expert Technical Team through the Institutional Organizers will provide the necessary technical input to institutionally strengthen this organization.

A numerical example for computing number of agrowells in a sub-watershed encompassing a tank is given in **Annexure 7**.

6 IMPLEMENTATION STRATEGY FOR WATER DEVELOPMENT COMPONENT

6.1 Organizational Structure

This study has focused on the water resources development component of the proposed area development project of the NCP. This means that water resources development is only a key component of a set of various other rural development activities that would be undertaken by the project. Thus, it is not logical to consider water resources development in isolation in mapping out an implementation strategy. Nevertheless, the implementation strategy must be capable of accommodating water resources development as well as other multiple development activities of the project including land management, marketing, agro-industries, value adding, etc.

Water resources development, or more specifically rehabilitation of tanks and other physical improvements such as agrowell development etc; are necessary but not sufficient requirements or elements of integrated land and water management in the context of a broader area development framework. On the other hand, integrated land and water management should take a holistic approach involving not only irrigated agriculture, but also rainfed farming in uplands, related agro-industries and services, and land and water resources conservation too, if the ultimate goal of area development is to ensure the well being of the people of the NCP targeted under this area development programme. In both short- and long-run, the well being of the people depends, to a considerable degree, on how capable they are to: exploit higher production and productivity levels from the available land and water resources base; improve, if not sustain, the production potential of the resource base, and; secure higher incomes from their production through value-adding, agro-industries and efficient service system including marketing.

Thus, organizational structure required for water resources development proposed herein had emerged from the above conceptual framework as well as from the analysis given in the preceding chapters of this consultancy report, which considered the tank cascade or sub-watershed as the basic unit of operation for integrated land and water management. Thus, the basic aspects of the proposed organizational structure had emerged from the:

1. need for organized group action by the land and water users for related activities; and

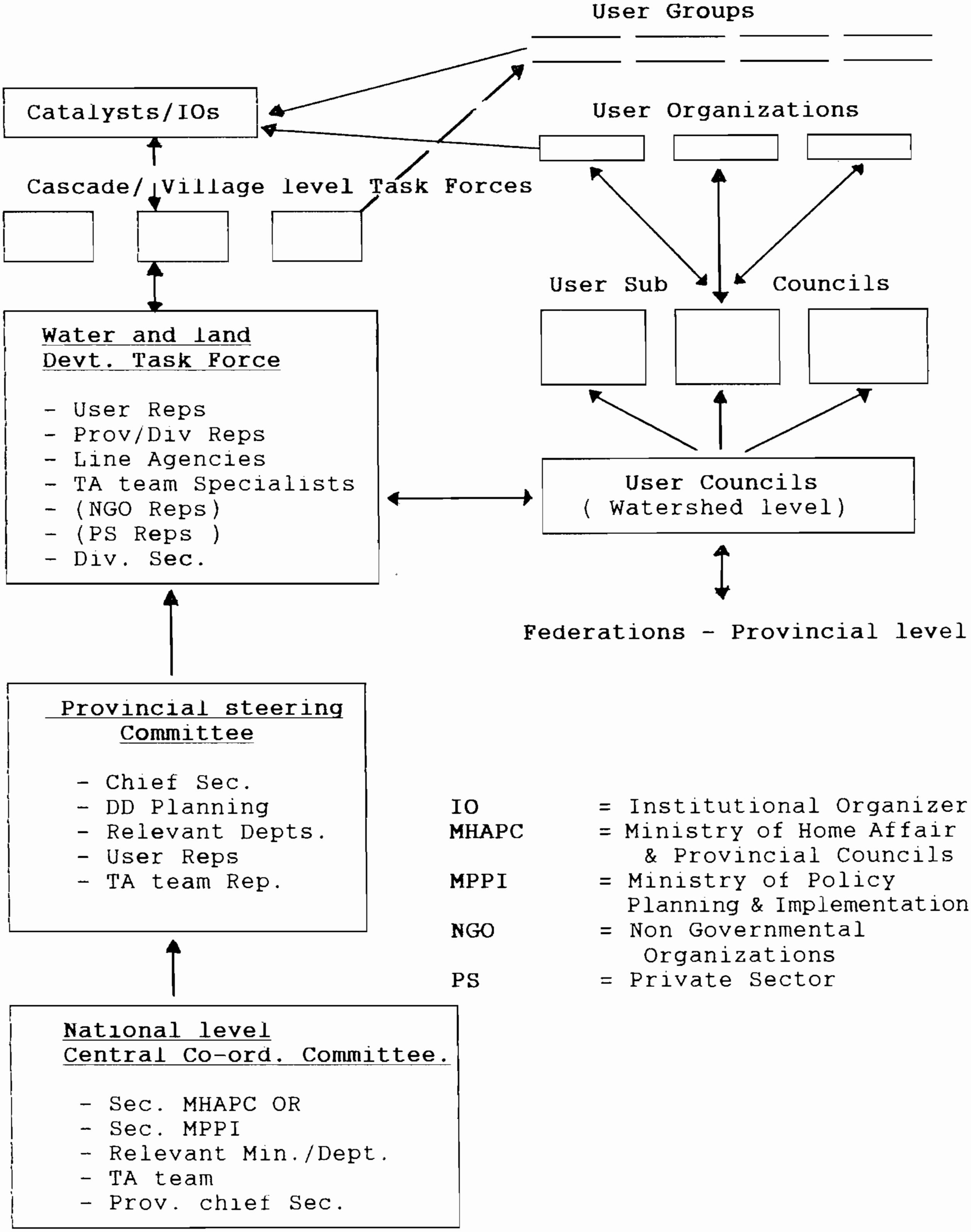
2. need for technical inputs, services, and other support services to user groups/beneficiary organizations to carry out various technical, managerial and organizational activities required for land and water resources development as suggested in this guidance package; and

3. need for institutional strengthening the user groups/beneficiary organizations.

The proposed Organizational Structure of the Project considers these demands. It is illustrated in **Figure 1**. The project will be implemented primarily by the user groups with the help of

Catalysts/Institutional Organizers (IO) at the field level. Field activities will be supported by a multi-disciplinary team of professionals operating at provincial level and relevant line agencies. The **base activity unit** will be the tank-cascade system including village settlements, paddy areas, highlands and chena. The project activities at this level will be coordinated by the IO. A small task force composed of the IO (co-ordinator), farmer representatives and concerned government officials (eg: Agriculture Instructor, Grama Niladhari, Technical Assistants, etc.) will be responsible for planning and day-to-day implementation and M&E. The catalyst/IO will be the only 'new recruit' for the proposed task force and, therefore, will not demand heavy financial commitments. A limited cadre of catalysts/IOs may be recruited by the project to cover the entire activity area of the Project. A highly qualified locally recruited multi-disciplinary team of professionals stationed at the provincial level will provide technical assistance (TA). The Planning Officer/Asst. Director (Planning) located at the Divisional level will act as the LINK between this TA team and the village level task force. Thus, the proposed organizational structure is cost-effective.

Figure 1. Proposed Organizational Structure



IO	= Institutional Organizer
MHAPC	= Ministry of Home Affair & Provincial Councils
MPPI	= Ministry of Policy Planning & Implementation
NGO	= Non Governmental Organizations
PS	= Private Sector

The TA team will have the following:

(1) The Institutional Development Specialist with experience in organizing farmers, training and skill development, co-ordination and with strong interpersonal and training skills.

(2) An Agronomist/Conservation Farming Specialist with a good knowledge in conservation farming, water saving techniques, crop husbandry, rainfed agriculture, agricultural extension and farm management.

(3) An Enterprise/Marketing Specialist with diverse experience in enterprise development, linking farmer groups with appropriate markets/private sector, co-operative business ventures, etc.

(4) Hydrologist with experience in irrigation design, agrowell design and operation, irrigation and drainage (O&M), farmer organizations, rainfed agriculture. (A senior professional from the Irrigation Department or Agrarian Services Department may provide this input on a part-time basis.)

One member will act as the coordinator and will oversee overall project implementation activities on a day-to-day basis. If project funding for an external Technical Assistance Team is a constraint, the multi-disciplinary TA team can be formed by drawing expert professionals from the public service to work on secondment basis.

At the Divisional level, there will be a Task Force/Co-ordinating Committee **chaired by the Divisional Secretary**. The Planning Officer/Asst. Director, Planning will act as the Secretary/Convener. The Committee will be composed of user representatives, concerned line agency representatives, relevant NGOs, if any, and TA team representatives. Alternatively, following SCOR project approach, this Task Force/Coordinating Committee may be established at the watershed level. Apart from the TA team, all other members of the task force/committee will be drawn from line agencies, NGOs, and Farmers' organizations. Hence, no additional costs will be involved.

At the provincial level, there will be a Steering Committee chaired by the Provincial Chief Secretary. The Deputy Director, Planning will act as the Secretary/Convener and the committee will be represented by TA team, farmer organization federation/council, concerned line agencies such as Department of Irrigation, Agrarian Services and Agriculture Department, etc. At this level too, no additional costs will be involved as in the case of Divisional Level described above.

There will be a Central Coordinating Committee at the National level, chaired by the Secretary of the Ministry of Home Affairs and Provincial Councils or Secretary, Ministry of Policy Planning. Other relevant Ministries, Departments and the TA team, Provincial Chief Secretary, Provincial Deputy Director, Planning, etc. will be included in this committee. Its specific responsibilities will include:

- review project progress; examine any discrepancies between planned and actual achievements and make recommendations for accelerating progress in the upcoming quarter;

- reviewing and approving the quarterly and annual workplans, recommend changes, if necessary;

- facilitate progress by adding to the efforts of PSC, watershed resources management team and other implementors;

- discuss and resolve specific policy/and or procedural impediments.

The proposed Provincial Steering Committee will perform a similar role at the Provincial level.

It is proposed to devolve authorities of project implementation decisions to lower levels. And, it is proposed to nominate a senior official of the host ministry (Ministry of Home Affairs and Provincial Councils or Policy Planning) as the National Level Facilitator/Coordinator. Her/his responsibilities will include:

- Planning and convening meetings of the NSC in consultation with Project Leader;

- Recording and communicating the decisions of the NSC to the parties concerned;

- Make independent visits to project sites as necessary;

- Help resolve policy/procedural impediments, if any, through discussions with the staff of relevant agencies, provincial and divisional authorities and provincial professional team of project;

- Facilitating and ensuring the harmonious functioning of project management by promoting the effective participation of all concerned agencies, and

- Representing the host Ministry in the Provincial Steering Committee.

At the provincial level, Secretary to the PSC, preferably the Deputy Director Planning, will assume similar responsibilities to facilitate the smooth functioning of project.

While the Steering Committees review and facilitate the project implementation, the responsibilities of the Provincial Professional Team (i.e. TA team) will include:

Catalyzing all aspects of project implementation:

- providing professional expertise for project implementation;

- prepare workplans and budgets, in consultation with user groups and line agencies at sub-watershed and Provincial levels;

- conduct regular reviews and analyses;

- arrange for specialized assistance when necessary; including preparation of terms of reference, work supervision and evaluation;

- providing guidance and technical advice to the NSC, Coordinating Committees or task forces at lower level and catalysts;

- developing close links and working relationships with relevant GOSL or other donor funded projects operating in the area.

Co-ordinate and Monitor all project activities.

- Sub-contracting project activities, if necessary.

- Aggregating project reporting at sub-watershed and provincial levels;

- Attending to other functions that may be decided upon by the NSC or PSC.

6.2 Implementation Strategy

Proposed Process for Integrated Land and Water Management in Sub-Watersheds/Cascade Systems

For agricultural and related development activities, it is proposed to focus project efforts on sub-watersheds/cascade systems. This will be the basic planning, coordinating and implementation unit. Project will promote integrated planning for land and water resources utilization in these basic units, gradually transforming the strategy of development of the resources from a "project" mode to a "programme" mode. In order to facilitate this process of internalization, the project will help strengthen the capacity of the provincial administration, divisional secretaries, line agencies and user groups at different levels[6].

In each sub-watershed/cascade system, **in addition to tank selection and design for rehabilitation,** the project will conduct a participatory assessment of the present land and water use patterns, capabilities of resources user groups and support services, socio-economic status, status of resource degradation and potential for development. Based on this assessment, the project will develop an integrated plan to improve land and water resources management in the areas, again, through a participatory approach. Planning will be focused on efforts to intensify the utilization of resources through known technologies, and also to augment the resources base.

These analyses will assess the current and potential status and uses of resources in the area and identify economic, technical, informational, institutional, or legal factors that prevent resource users from managing and utilizing land and water resources (as well as labor and capital) to best advantage while conserving the physical, biological and social environments. **Other than the experiences with institutional organizers in major irrigation systems and with "social mobilizers" in some areas/villages (for specific purposes), information and proven strategies on incentives and means for organizing beneficiaries for integrated land and water resources use and related industrial development (in a holistic manner) is very much limited. Hence, there is a need for the project to: organize user groups, provide appropriate technological packages, check and co-ordinate forward and backward linkages to promote and internalize environmentally sound novel productive enterprises.** To illustrate the participatory planning of production and protection processes at sub-watershed/cascade level, SCOR project experience is summarized in **Annexure 10.**

[6] This is essentially the SCOR approach to strike a balance between "production" and "protection" and to improve living standards of beneficiaries.

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ANNEXURE 1

THE SMALL TANK CASCADE SYSTEMS OF THE NORTH CENTRAL PROVINCE (NCP), THEIR DISTRIBUTION PATTERNS, GENERAL CHARACTERISTICS AND PROPOSED TYPOLOGIES

1. Introduction

A preliminary examination of the small tank cascades system as shown in the one inch to 1 mile topo sheets covering the NCP shows a great diversity of (a) forms or types, (b) size and shape, and (c) distribution patterns and tank density across the different land surfaces of this province.

An overall view of the broader picture could be obtained from a glance at the map **(Figure 2)** which shows the small tank cascade distribution pattern together with the natural drainage systems of the Anuradhapura district. (The Polonnaruwa district which comprises the eastern portion of the North Central Province has been excluded from this study because it is mainly made up of the larger irrigation tank systems).

The 75 percent probability value of annual rainfall is adopted as a more reliable index of rainfall expectancy than the mean annual rainfall for this tropical semi-humid climate. As seen in **Figure 2** it ranges from between 800 mm to 900 mm in the eastern aspects of the district to between 600 to 700 mm in the western aspects.

The natural questions that arises from an examination of **Figure 2** is (a) why is there a greater concentration of small tank cascades in certain parts of this district compared to the other parts of the district?, (b) what causes this variation?

At the next level, when examining the shape, form and size of the range of individual cascades in the 1 inch to 1 mile topo sheets it is observed that some cascades are elongated, some branched, some long and others short, etc. How could one develop a typology that would enable a grouping of these cascades into meaningful categories?

The next logical question would be what bearing does this shape and form, or the morphology of the cascade landscape, have on the hydrological endowment of the cascade?

On the basis of the preliminary field studies carried out within this limited period of 3 weeks supported by an analysis of the land forms and the geological and soil maps, and rainfall probability patterns in combination with the 1 inch topographic sheets, an attempt is made to address the questions and issues raised in the foregoing paras. It should be noted that with more detailed studies that could be conducted in the future more clarifications could be made.

2. Regional Drainage and Distribution Patterns

The Anuradhapura district is located within the lowest peneplain of the island and consists of a gently undulating to undulating land surface or a 'planation' surface. This land surface is characterized by the occurrence of a large number of both micro-catchments and meso-catchments as could be observed in **Figure 2**. The size of the micro-catchments range between 75 acres to 150 acres and that of the meso-catchments between 3,000 acres to 10,000 acres. **Figure 3** shows a generalized pattern of a meso-catchment at a scale of 1:50,000 together with its component micro-catchments as well as the location of the small tanks in a cascade form.

All small tank cascades are located within these meso-catchments which correspond to the second or third order inland valleys of this landscape.

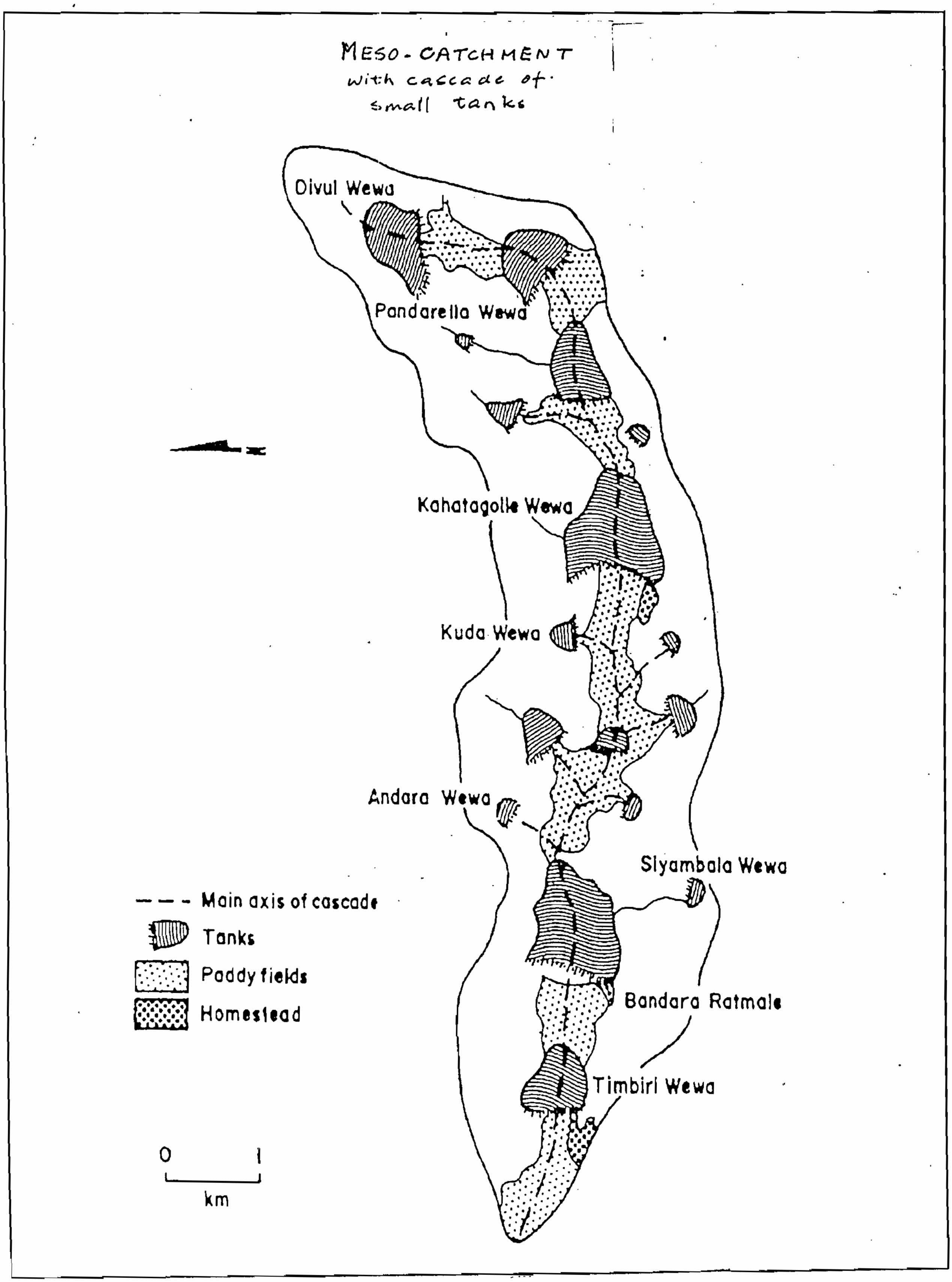
It could also the observed in **Figure 2** that all these meso-catchment basins or inland valleys drain into either a first or second order stream. These first and second order streams subsequently drain into the larger third order streams such as the Kanadara Oya and Maminiya Oya; which in turn drain into the final fourth order river such as the Malwatu Oya, Kala Oya, Yan Oya, etc. which drain into the sea.

The three main fourth order rivers - Kala, Malwatu and Yan Oyas, and the four main third order streams - the Moderagama, Kanadara, Maminiya and Ma Oyas have their main watershed areas located within the district itself except for a very minor portion in the south. The Yan Oya and Ma Oya flow in a north - north east direction within the smaller eastern segment of the district divided by the main central watershed divide which runs approximately north-south **(see Figure 2.** The Kala Oya, Moderagama Aru, Malwatu Oya, Kanadara Oya and Maminiya Oya flow in a north-north west direction within the larger western segment of the district. All these rivers show a dendritic drainage pattern and their direction is controlled mainly by the strike and trend of the underlying rock and direction of the major fault lines.

As could be observed in **Figure 2** the highest density of small tank cascades is found to occur in the upper aspects of Kanadara Oya, the Kadahatu Oya and the upper catchment area of the streams that drain into the Mahakanadarawa tank. A moderate density of small tank cascades is found to occur in the immediate catchment areas of the Nachchaduwa and Kala Wewa tanks. A lower density of small tank cascades is found to occur within the main catchment areas of the Yan Oya, Mora Oya, Moderagam ara and the lower aspects of the Malwatu Oya. The next section of this chapter will discuss the factors that could govern the tank densities in the different parts of the district.

It should also be noted that there is a very small percentage of small tanks that do not occur within a cascade, but as individual tanks with their own independent micro-catchment. A well known example being that of the Pul Eliya tank village close to Medawachchiya studied by Leach in 1956 and often cited by social science researchers.

Figure 3. Meso Catchment with Cascade of Tanks



3. Factors Governing Distribution Patterns and Tank Densities

A preliminary examination of the shape and form of the landscape, also termed land-form, reveals that the distribution patterns of the small tank cascade systems as well as the small tank density of the region is primarily governed by the land-form type of the region together with the natural drainage pattern.

A land-form may be defined as a unit of land that is homogeneous from the point of view of origin and morphology, or heterogeneous with a repetition pattern of two or more landscape elements. The dominant landform of this lowest peneplain has been previously (1963)* identified as the 'mantled plain' which usually designates a gently undulating to rolling plain with a mantle of residual materials derived by weathering from the underlying rock. This mantle consists of both the residuum of underlying weathered basement rock and the soil profiles developed in its upper part. Four topographic classes of mantled plain are recognized as follows:

Flat or nearly level	-	0-2% slope range
Gently undulating	-	2-4% slope range
Undulating	-	4-8% slope range
Rolling	-	over 8% slope range

The higher small tank cascade density as shown in **Figure 2** is mainly confined to those areas having a gently undulating relief with the surrounding terrain consisting of slopes of less than 4 percent. The lower small tank cascade density is mainly confined to those areas having an undulating relief with the surrounding terrain consisting of slopes of between 4 to 8 percent. This relationship was clearly observed during the field studies.

Although it could be argued that there should be a higher tank density in areas that receive a higher rainfall, this does not always follow because the nature of the land-form can exert an overriding influence. This is best illustrated within the Yan Oya catchment basin located within the eastern segment of the district in **Figure 2**, where despite the higher rainfall a lower tank density is observed because of the greater relief of the land-form which corresponds to undulating to rolling with slopes of 4 to 8 percent or more.

However in the western segment of the district which has a lower rainfall than the eastern segment the density of small tank cascade is significantly lower as could be seen in **Figure 2.**

The decrease in small tank cascade density with increasing local or regional relief of the surrounding landforms is also clearly observed in **Figure 2** which shows a decreasing density west of the Kala Wewa - Nachchaduwa - Anuradhapura - Medawachchi transect.

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* 1963 Report of 15 River Basins of North West Ceylon. Government Press. Colombo.

The lithology of the underlying basement rocks as well as the permeability of the overlying soil profile could also exert a significant influence on the tank density of the area. For example, the area east of Anuradhapura is made up of the Highland series of Precambrian rocks consisting of charmockite gneisses and some metasediments, while the area west of Anuradhapura is made up of the Vijayan complex consisting of gneisses, migmatites and granitoids.

Correspondingly the nature of the soil overburden also exerts an influence on the tank density of the area. For example, the very low tank density that is observed north west and south east of the Maha Willachchiya tank in the Moderagama aru area is primarily determined by the very porous and highly permeable nature of the soils that occur in this part of the district. It could also be further observed that the Aluthwewa soil catena which occupies the eastern and central segment of the district has more compact and less permeable soils profiles than the Ranarewa catena which occupies the south western segment and which has less compact and more permeable soil profiles.

Overall, the factors that govern the distribution patterns and tank densities of the small tank cascade surplus could be ranked as follows:

1. Geomorphology of the landscape - mainly landform type.

2. Rainfall - amount and season

3. Nature of the underlying geology or lithology; and nature of the soil profile overburden.

Further research would need to be conducted by a post-graduate university member in order to work out the essential nature of the relationships between the foregoing factors in as far as they influence the pattern and density of the small tank cascade systems in this environment.

4. General Characteristics and Proposed Typologies of Small Tank Cascade Systems (STCs)

As discussed in the preceding sections, the morphology or the shape and form of the small tank cascade systems (STCs) are very closely related to the configuration of the landscape within which they are situated.

A demarcation of the catchment or the watershed boundary of an individual STCs on the 1 inch to 1 mile top sheet clearly brings out the two dimensional characteristics of the spatial shape and form of the cascade with respect to the position of the main central valley, the side valleys, the component individual small tanks and the tank density within the meso-catchment. An example is shown in **Figure 3** which shows the main valley, side valleys and small tank distribution pattern.

As a preliminary exercise it should not be too difficult to demarcate the catchment or watershed boundaries of each and every STCs in the Anuradhapura district. But this would be too time consuming at this preliminary stage and could be conveniently deferred to a later stage. As an alternative approach the watershed boundaries of twenty small tank cascades were demarcated on the 1 inch to 1 mile topo sheets which gave a first approximation of the range of STCs with respect to size, form and shape.

From the above twenty, the following five small tank cascades were selected on the basis that these five could be representative of the rest of the STCs in the district.

1. Maha Kanamulla cascade
2. Tirappane cascade
3. Ullagalla cascade
4. Gangurewa cascade
5. Timbiriwewa cascade

These are shown demarcated in **Figure 2**. The Tirappane and Maha Kanamulla cascades were included in this selection because considerable prior studies had been already carried out on the hydrology and water balance by IIMI scientists from 1991 on the Tirappane cascade; and agronomic and groundwater studies by the Maha Illuppalama research scientists of DOA on the Maha Kanamulla cascade since 1989. The results of the foregoing studies could thus be profitably utilized in establishing meaningful relationships between those findings and the main characteristics of the other cascades.

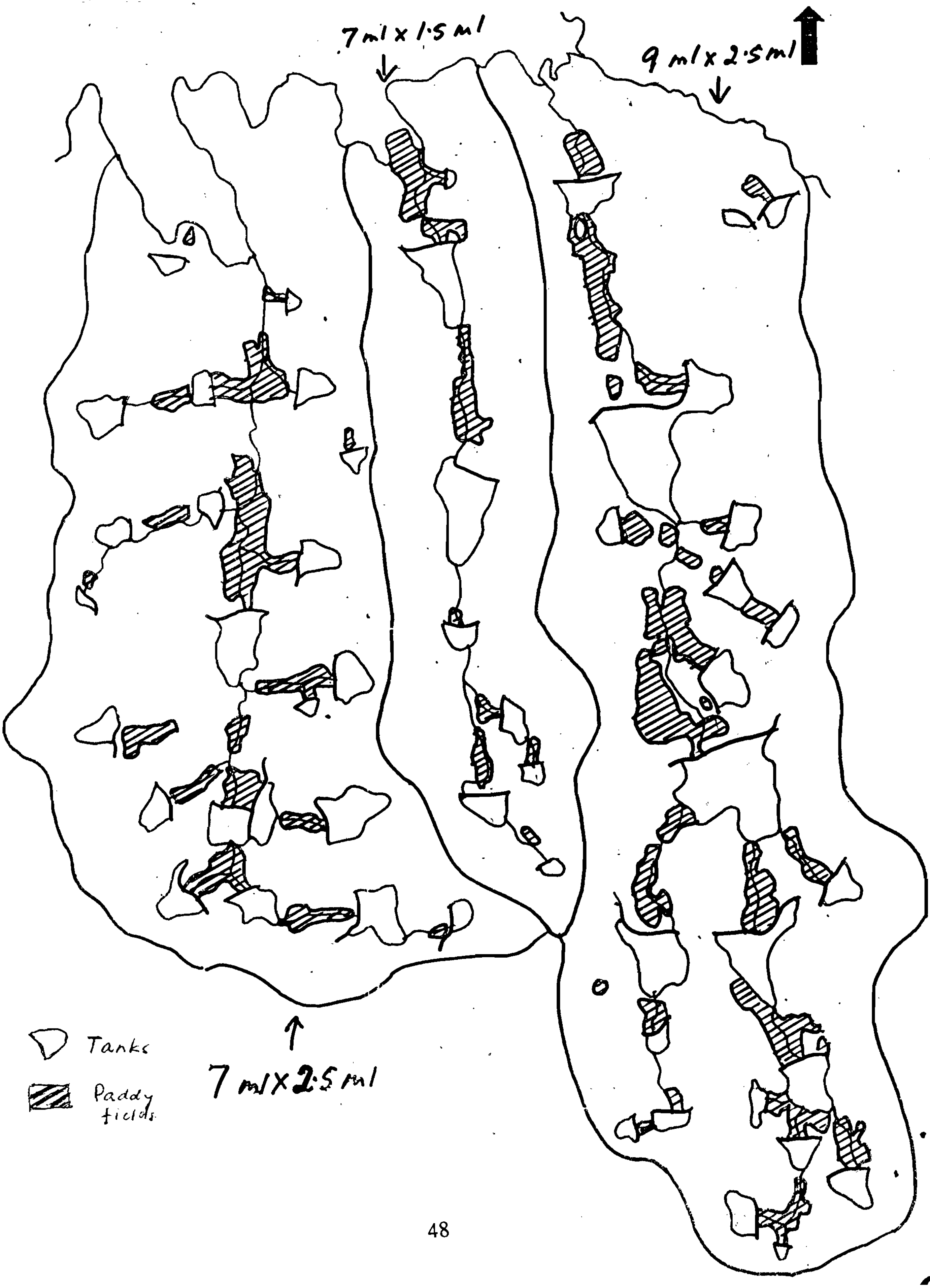
As mentioned earlier, the STCs of this district are of varying form, size and shape in their make up and composition. Some are long and narrow in form with a dominant main valley and sub-dominant side valleys as in the case of the Tirappane cascade shown at scale 1 inch to 1 mile in **Figure 4**. Others could be long and broad in form, with several branched side valleys as in the case of the Kanamulla cascade also shown in the same scale in **Figure 4**. There are others that could be considered transitional in form to the above two cascades as for example the Timbiriwewa cascade shown in **Figure 2.**

Based on a study of a total of 12 STCs both on the 1 inch to 1 mile topo sheets together with supporting field studies on the ground to check the correct disposition and arrangement of the individual component small tanks, the central valley, side valleys and the watershed boundaries one could arrive at a broad typology as follows.

1. Linear
2. Branched
3. Transitional

The above could be considered as the first or highest level of characterization of the STCs of the district and is demoted by prefix L1.

Figure 4 **MAHAKANUMULLA, THIRAPPANE, AND ULAGALLA CASCADES**



The second level of characterization L2 of STCs is essentially descriptive and helps to provide a figuration characterization of the cascade. Based on a field study of the 12 STCs mentioned earlier, the following parameters were selected as being most significant in terms of characterization at this second level L2.

These parameters are referred to as descriptors and constitute the following:

1. Size - large, medium, small

2. Length - long, short (form)
   straight, irregular (shape)

3. Breadth - broad, narrow

4. Location of side valleys
   - head-end
   - middle
   - tail-end

The third level of characterization L3 is one that takes into account those parameters that have a profound influence on the hydrological endowment of the particular cascade. For this purpose it was decided to study the general hydrological behavior of the five STCs shown in **Figure 2** for which significant data such as (a) the cropping intensity of the individual tanks within the cascade were available over the last five consecutive maha seasons, and (b) degree of retention of the surface water storage of the tanks within the cascade. Both of these provide an integrated index of the hydrological endowment of the cascade. These were correlated with the detailed hydrological data of J. Itakura carried out over the period (1991-1994) and published in 1994 as IIMI Working Paper No.24.

In the foregoing studies it has been clearly brought out that the landform of the meso-catchment and its surroundings together with the slope of the axis of the main valley are the key determinants, apart from the amount of seasonal rainfall that govern the hydrological endowment oft he STCs. With respect to individual tanks, the ratio of catchment area to tank area was a significant parameter. However with respect to the overall cascade this was found not highly significant.

The following determinants have therefore been adopted or the third level of characterization L3 of the small tank cascade systems.

1. Land form of meso-catchment and its surroundings:

   Gently undulating - 1.0 - 3.0 percent
   Undulating - 3.0 - 5.0 percent

2. Slope class of axis of main valley:

Gently sloping	-	0 - 2.0 percent
Moderately sloping	-	2.0 - 4.0 percent

The following sub-determinants are significant in respect of the individual tanks within a cascade.

(a) Location or position of the individual tank at the confluence of two side valleys within the main valley.

(b) The catchment area to tank area ratio.

(c) The presence of rock outcrops and rock-knob-plains (RKP) in the immediate catchment of the tank which enables a high runoff compared to forest cover.

To further elaborate on the significance of the first of the two key determinants one could show the relationship between the landform type and the mean cropping intensity for each cascade in the tabulation below.

	Cascade Name	Landform type	Mean Cropping Intensity (CI)
1	Tirappane	Undulating 3-5% slope	69
2	Maha Kanamulla	Undulating 3-5% slope	62
3	Gangurewa	Gently undulating 1-3% slope	84
4	Timbiriwewa	Gently undulating 1-3% slope	82

The slope class of the axis of the main valleys could not be measured in all cascades in the field due to lack of time and resources. However, a qualititative estimate of the slope classes were made during the field studies which showed the higher slope class in the Tirappane cascade and lower slope class in the Gangurewa cascade.

The significant characteristics of five small tank cascade systems expressed in terms of their typology, descriptors and determinants is shown below.

	Name of Cascade	Typology	Descriptors	Determinants
1	Tirappane	Linear	Medium Long, straight Narrow, uniform Few side valleys	Undulating Axis - moderately sloping
2	Maha Kanamulla	Branched	Large Long - irregular Broad - non uniform Many side valleys and confluences	Undulating Axis - moderately sloping - gentle sloping in middle
3	Ullagalla	Linear	Very large Long - straight Broad - wavy Many side valleys at head and middle Many RKPs at head-end	Undulating Axis - moderately sloping
4	Gangurewa	Branched	Large Short - irregular Broad - non-uniform Few side valleys	Gently undulating Axis - gently sloping
5	Timbiriwewa	Linear	Medium Long - curved Narrow - headend Broad - tailend Few side valleys	Gently undulating Axis - gently sloping

INDICATORS AND CRITERIA FOR SELECTION OF TANKS FOR REHABILITATION

Data related with a sample of 51 selected tanks were analyzed with a view to identify the correlation between the hydrologic and physical parameters of those tanks and their agricultural performance as reflected by the Cropping Intensity. This study revealed the following facts.

(a) 51% of the sample tanks have an average water depth of between 7 to 8 ft, as shown in **Figure 5**. Tanks having a water head more than 7.5 ft on average, had higher Cropping Intensities. The same correlation was observed by Somasiri (1991) which recommended that tanks having a water depth more than 8 ft had a higher irrigation potential. The plotting of tank water heads against CI in **Figure 5** shows the concentration of the tank water head between 7 and 8, although some tanks having water depth more than 7 have a lower CI due to reasons explained later in this section.

(b) There exists no clear correlation between CI and Catchment Area/Tank Capacity, Capacity/Command Area, and Catchment Area/Command Area ratios. However, the range of Catchment Area/Tank Capacity ratio values of a large number of tanks fall in between 2 and 3, the average being 2.5. Also, the range of tank Capacity/Command area ratio of a large number of tanks falls within 2 and 4, the average is around 3.0.

(c) The study shows that tanks having a higher Catchment Yield/Tank Capacity (Y/C) ratios have higher CI values. This ratio, hypothetically indicates the number of times a tank would fill completely (spill) during an average Maha season, and therefore, reflects the 'hydrological richness' of a given tank. Tanks having a Y/C ratio more than 2.25 appear to have very higher CIs generally. Thus, based on the results, it is assumed that a tank should have a minimum Y/C ratio of 1.50 to perform satisfactorily.

(d) The minimum Y/C ratio (1.50) is used to develop indicators to assess the 'hydrological richness' of a given tank and the adequacy of tank capacity to meet the irrigation requirements of its command area. These indicators will be used, as explained in Section 5.3, as the key indicators for selecting a given tank for rehabilitation, determining the nature of rehabilitation works; and level of rehabilitation investments.

(e) The storage capacity of a minor tank (V) is related to its water spread area (A) and water depth (d) at its full capacity by the approximate formula $V = 0.4 * A * d$, where V, A and d are measured in ac.ft, acres and ft. respectively. If we assume that, on average, a tank should have a water depth of 7.5 ft or more to perform satisfactorily, based on out finding, the above relationship simplifies to $V = 3\ A$.

(f) Using approximation V = 3 A, Y/C = 1.5 and the 75% probability rainfall for Maha for the NCP (see the **Annexure 3** on 'Hydrological Analysis' of this report), Catchment Area/Tank Capacity and Tank Capacity/Command area ratios of the sample tanks have been converted to and plotted as Catchment Area/Water Spread Area (CCA/WA) and Command Area/Water Spread Area (COA/WA) ratios. It is now seen that CCA/WA and COA/WA ratios of the tanks concentrate around 7.5 and 1.0 respectively. **(Figures 6 and 7).**

(g) Thus, it can be concluded that in the NCP, a minimum CCA/WA ratio of 7.5 is required for a tank to perform well hydrologically. This means a tank having CCA/WA ratio much larger than 7.5 would have a higher hydrological potential. Also, COA/WA ratio of a tank should be limited to or less than 1.0 to have an adequate tank capacity. This means, theoretically, a tank should ideally have CCA/WA >> 7.5 and COA/WA << 1.0 for it to perform efficiently both hydrologically and agriculturally.

(h) The conclusion in section (g) above can be further elaborated as follows. A tank of a given water spread area should have a Catchment Area (CAA) at least 7.5 times of its WA to have a sufficient catchment inflow. The catchment inflow can be effectively stored in the tank and used for irrigation without excessive losses only if the COA/WA ratio is less than 1.0.

(i) Thus, as explained later, the indicators and criteria CCA/WA > 7.5 and COA/WA < 1.0 are used together with Cropping Intensively (CI) as the key indicators and criteria for selection of tanks for rehabilitation. See Section 5.3 for detail description on the use and application of the indicators and criteria.

Figure 5 **Cropping Intensity Vs Full Supply Depth Level**

Minor Tanks in Anuradhapura Dry Zone

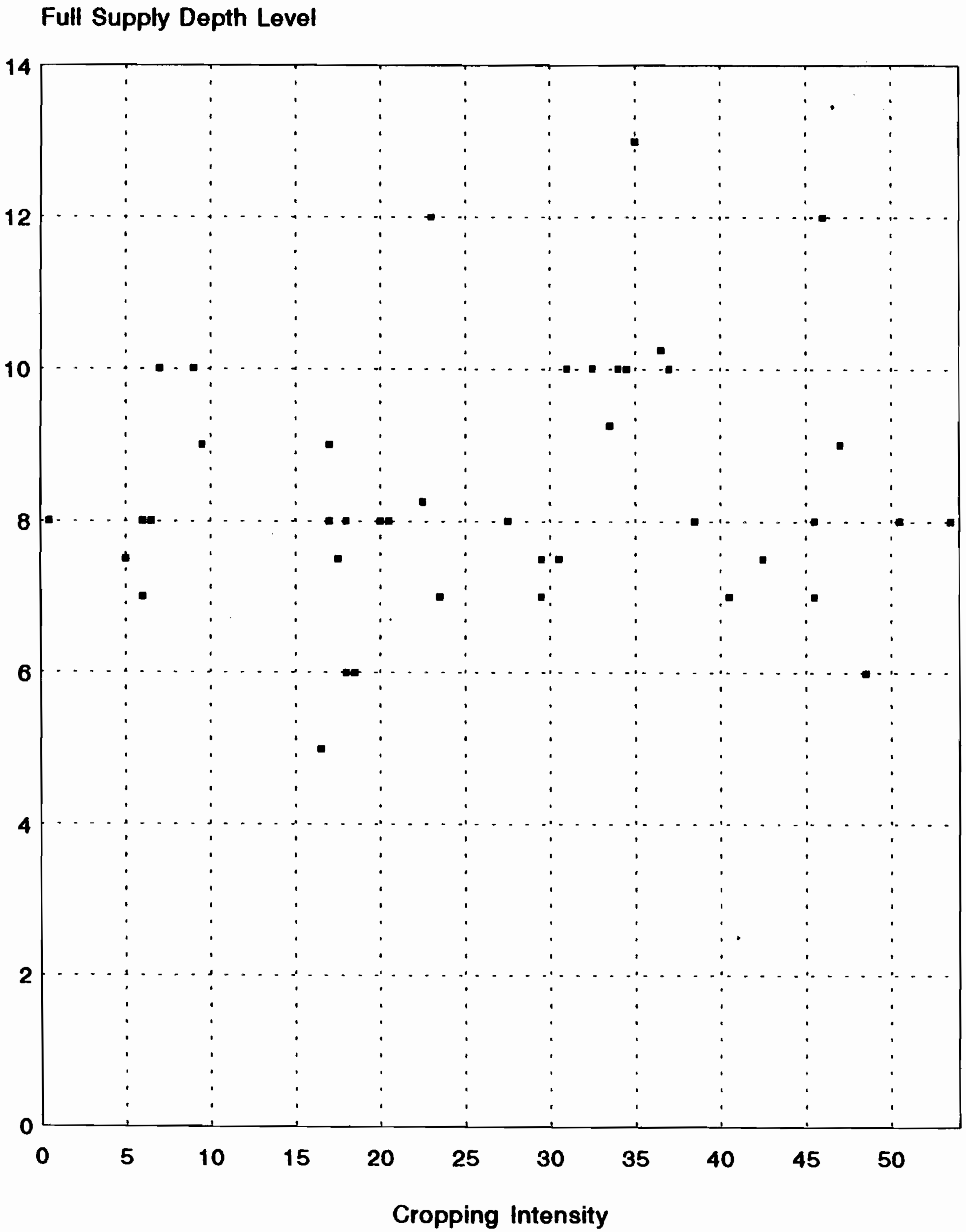


Figure 6 Cropping Intensity Vs Catchment / Water Spread Area Ratio

Minor Tanks in Anuradhapura Dry Zone

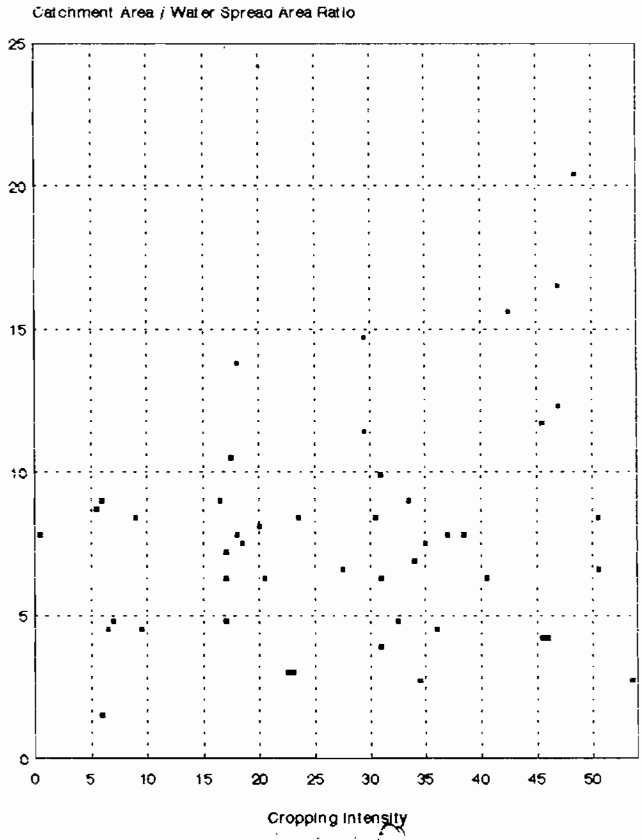
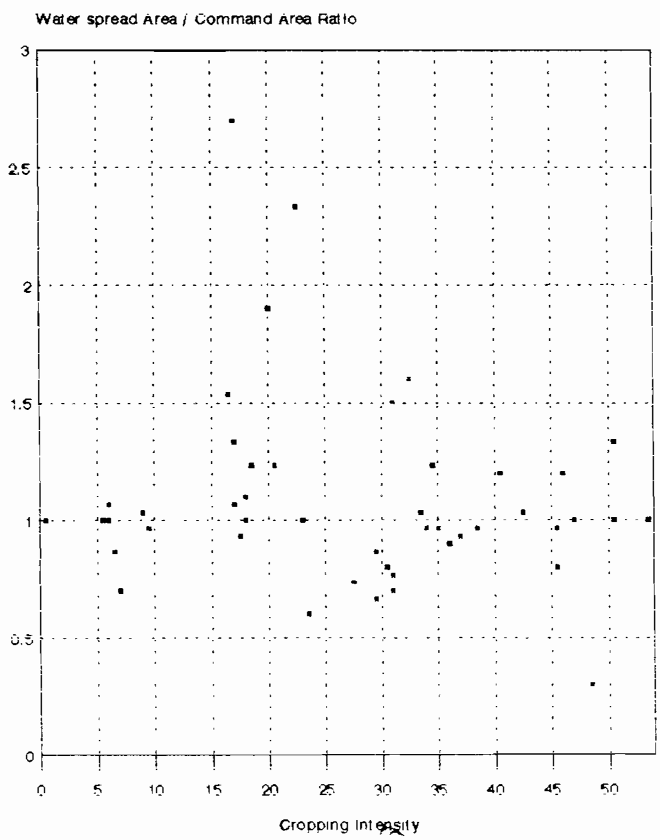


Figure 7 Cropping Intensity Vs Water Spread Area / Command Area Ratio

Minor Tanks in Anuradhapura Dry Zone



A REVIEW OF THE HYDROLOGICAL PARAMETERS

PART I - RAINFALL ANALYSIS

At present, design of minor tanks for restoration and rehabilitation is done on the basis of pre-computed monthly rainfall values. These values correspond to monthly rainfall having a 75% probability of exceedence in any given year for a given agro-ecological region.

The entire North Central Province (NCP) is represented by the agro-ecological region DLI as indicated in the original agro-ecological region map of Sri Lanka prepared by the Land and Water Division of the Agriculture Department. The contours of average seasonal catchment yield for the region (NCP) are shown in **Map 1.** This region has now been further sub-divided to three sub-regions as shown in **Map 2,** based on variation of rainfall over the NCP. However, at present, the entire NCP is considered a single region for tank rehabilitation design. This section discusses the consequences of that consideration.

Map 3 shows the river basins and the location of rain gauge stations in the NCP. Fairly long records of rainfall are available for these 13 stations. **Figure 8 and Table 2** show comparisons of 75% probability rainfall for those individual·stations with that of the DLI agro-ecological region presently used for tank rehabilitation design. The comparison reveals the following:

(a) There is a significant variation of 75% probability rainfall over the NCP.

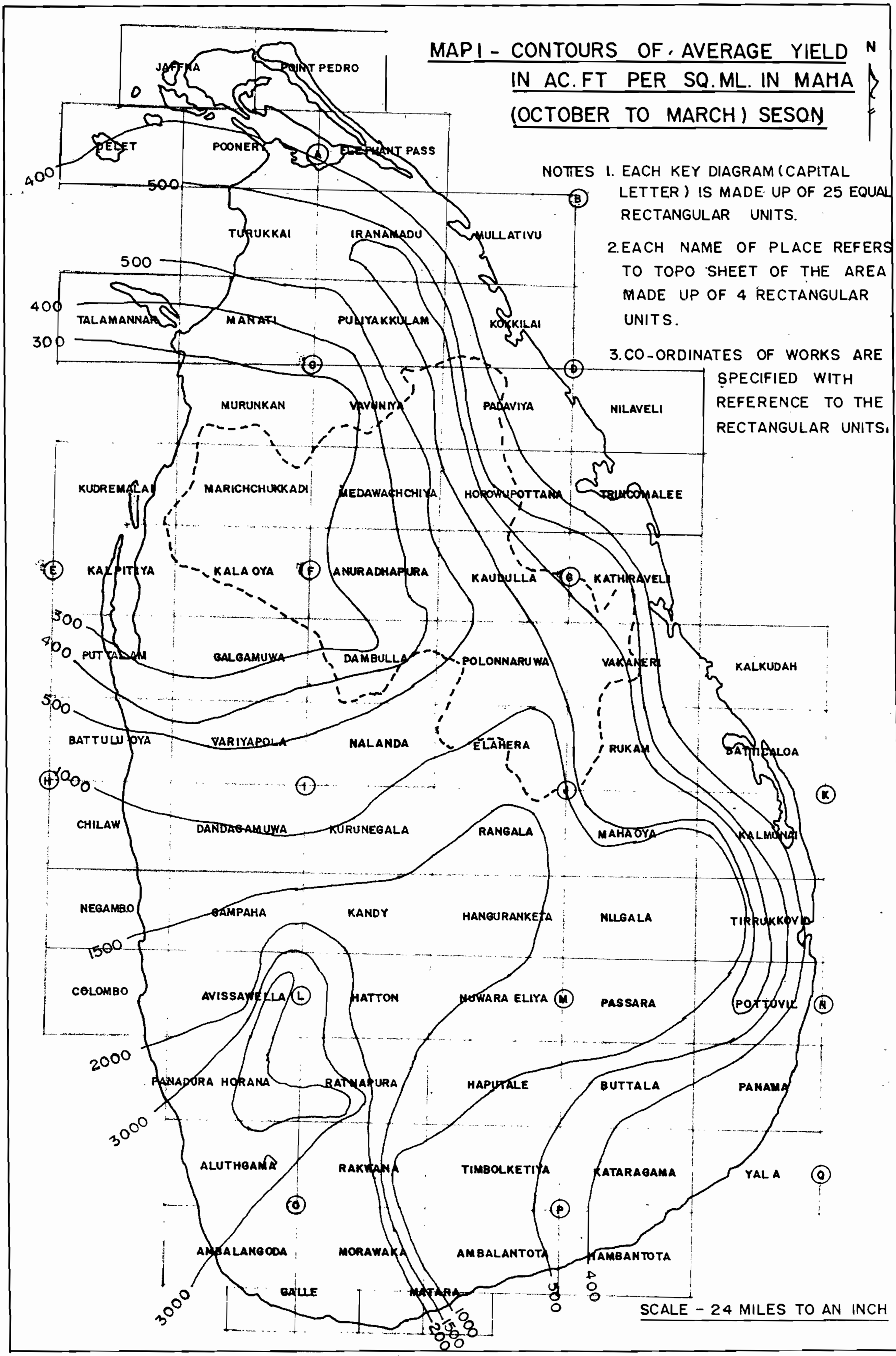
(b) The 75% probability rainfall for DLI is almost the modal value of the corresponding 75% probability rainfall values for the individual 13 stations.

(c) Rainfall is higher in the North Eastern part of the NCP, while it is comparatively lower in the South-Western part.

The above phenomenon can be represented by grouping the 13 rain gauge stations into three clusters as shown in **Figure 8 and Map 3.**

(d) The variation of rainfall over the NCP is correctly represented by the three sub agro-ecological regions shown in **Map 2.**

(e) The boundaries of the sub ago-ecological regions of the NCP by and large coincide with the boundaries of the major river basins.


MAP I - CONTOURS OF AVERAGE YIELD IN AC. FT PER SQ. ML. IN MAHA (OCTOBER TO MARCH) SESON
N
NOTES 1. EACH KEY DIAGRAM (CAPITAL LETTER) IS MADE UP OF 25 EQUAL RECTANGULAR UNITS.
2. EACH NAME OF PLACE REFERS TO TOPO SHEET OF THE AREA MADE UP OF 4 RECTANGULAR UNITS.
3. CO-ORDINATES OF WORKS ARE SPECIFIED WITH REFERENCE TO THE RECTANGULAR UNITS.
SCALE - 24 MILES TO AN INCH
JAFFNA
POINT PEDRO
DELFT
POONERYN
ELEPHANT PASS
TURUKKAI
IRANAMADU
MULLATIVU
TALAMANNAR
MANATI
PULIYAKKULAM
KOKKILAI
MURUNKAN
VAVUNIYA
PADAVIYA
NILAVELI
KUDREMALAI
MARICHCHUKKADI
MEDAWACHCHIYA
HOROWUPOTTANA
TRINCOMALEE
KALPITIYA
KALA OYA
ANURADHAPURA
KAUDULLA
KATHIRAVELI
PUTTALAM
GALGAMUWA
DAMBULLA
POLONNARUWA
VAKANERI
KALKUDAH
BATTULU OYA
VARIYAPOLA
NALANDA
ELAHERA
RUKAM
BATTICALOA
CHILAW
DANDAGAMUWA
KURUNEGALA
RANGALA
MAHAOYA
KALMUNAI
NEGAMBO
GAMPAHA
KANDY
HANGURANKETA
NILGALA
TIRRUKKOVIL
COLOMBO
AVISSAWELLA
HATTON
NUWARA ELIYA
PASSARA
POTTUVIL
PANADURA HORANA
RATNAPURA
HAPUTALE
BUTTALA
PANAMA
ALUTHGAMA
RAKWANA
TIMBOLKETIYA
KATARAGAMA
YALA
AMBALANGODA
MORAWAKA
AMBALANTOTA
HAMBANTOTA
GALLE
MATARA
A
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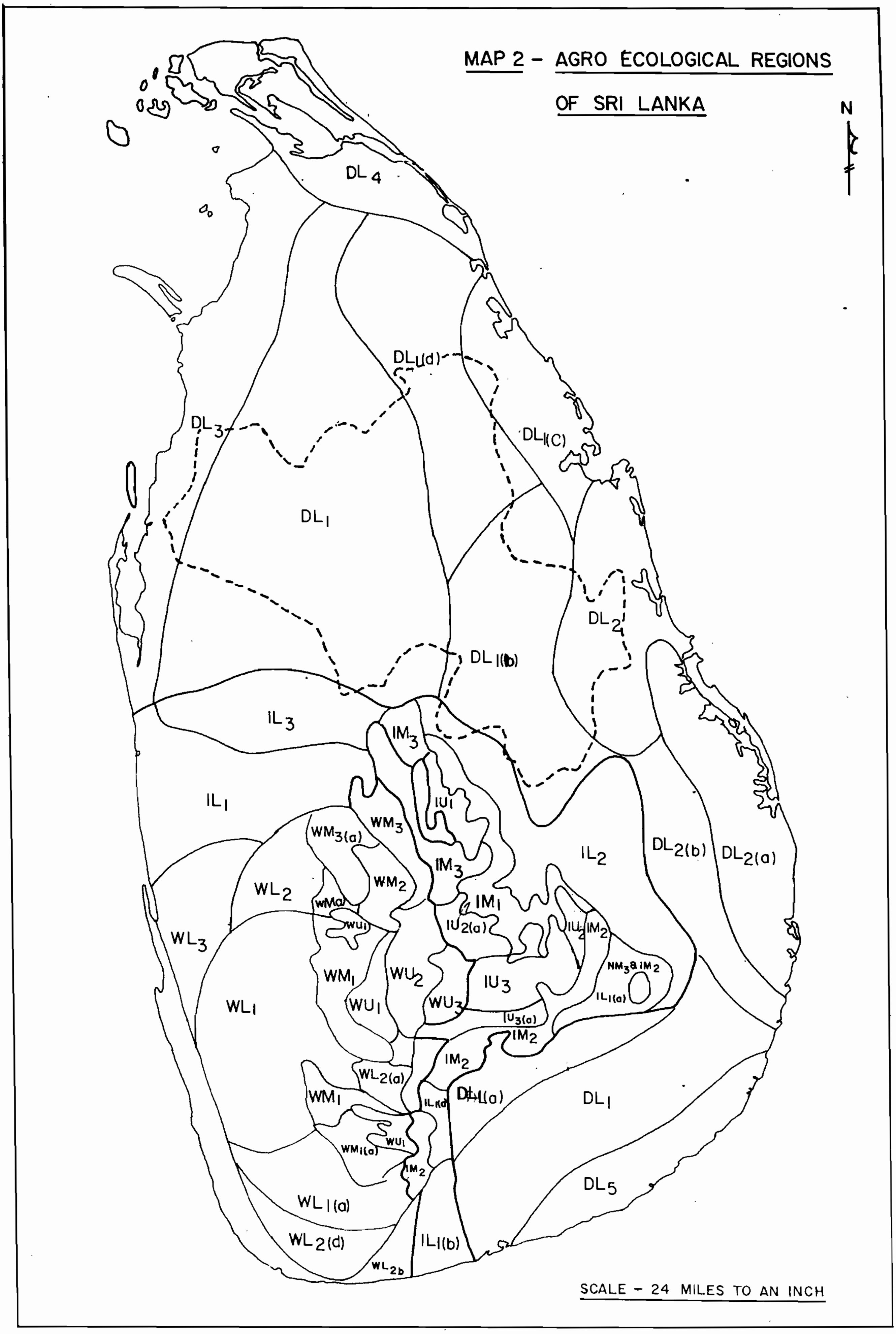
1500
2000



MAP 2 - AGRO ECOLOGICAL REGIONS OF SRI LANKA

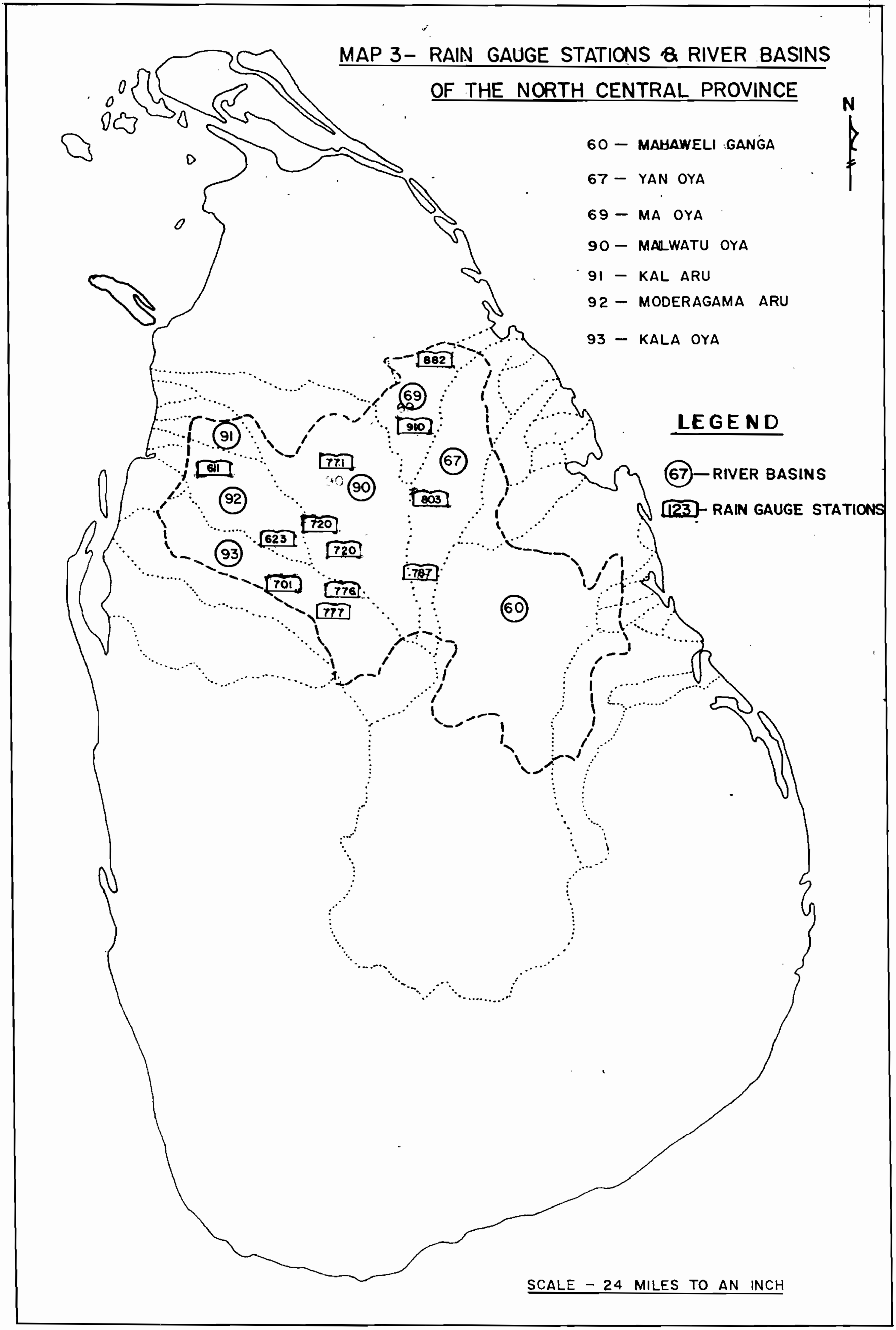

MAP 3- RAIN GAUGE STATIONS & RIVER BASINS
OF THE NORTH CENTRAL PROVINCE
N
60 — MAHAWELI GANGA
67 — YAN OYA
69 — MA OYA
90 — MALWATU OYA
91 — KAL ARU
92 — MODERAGAMA ARU
93 — KALA OYA
LEGEND
67 — RIVER BASINS
123 — RAIN GAUGE STATIONS
882
69
910
91
771
67
611
90
92
803
720
623
720
93
787
701
776
777
60
SCALE - 24 MILES TO AN INCH

Figure 8 75% Probability Rainfall for Maha
Anuradhapura Dry Zone

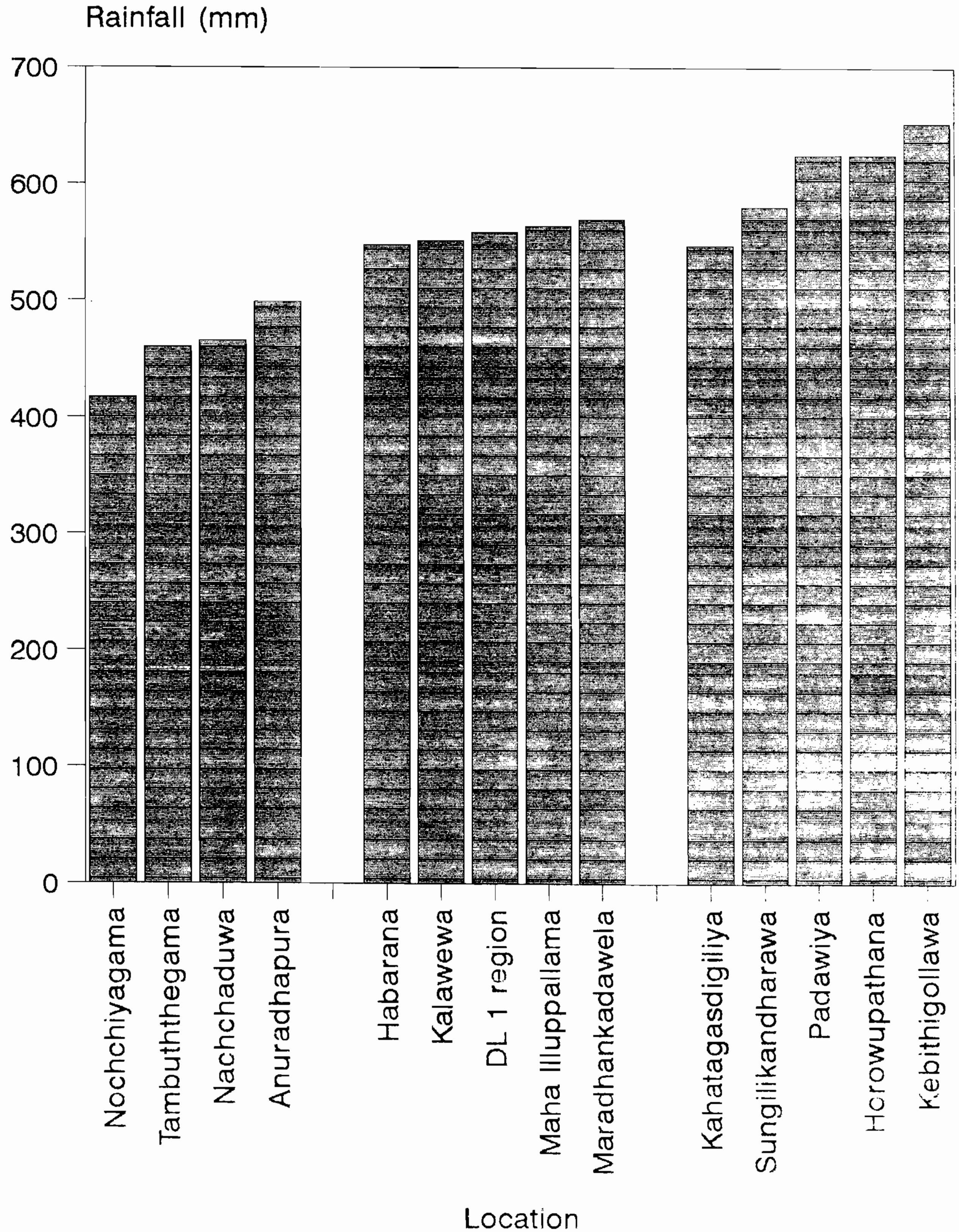


Table 2.

Comparision of Seasonal and Annual Rainfall at different Locations of the North Central Province

Season	Month	Location* 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Yala	APR	127	116	75	47	86	66	90	115	107	89	102	40	90	106
	MAY	51	41	27	44	44	48	29	46	39	32	48	27	33	68
	JUNE	13	5	4	12	15	8	8	3	8	5	11	18	16	6
	JULY	0	5	10	9	21	31	9	5	7	13	11	47	18	13
	AUG	13	7	12	44	30	56	8	4	11	11	7	35	22	18
	SEP	25	29	49	61	63	48	24	40	35	19	28	90	29	31
	Total Yala	229	203	177	216	258	256	168	213	206	169	206	257	207	241
Maha	OCT	127	154	118	134	153	146	147	179	152	144	132	155	139	131
	NOV	152	166	172	195	199	142	169	178	172	130	145	198	178	126
	DEC	127	102	179	175	188	137	122	130	128	107	80	207	117	82
	JAN	76	27	38	84	59	57	51	25	51	40	26	27	66	63
	FEB	25	15	34	18	25	36	18	16	20	14	8	24	25	8
	MAR	51	35	40	20	29	30	45	36	46	31	25	13	24	50
	Total Maha	558	499	581	625	652	547	552	564	569	466	417	625	548	460
	Total Annual	787	701	758	841	910	802	720	777	775	634	623	882	755	702

Location*

1 DL 1 region
2 Anuradhapura
3 Habarana
4 Horowupathana
5 Kabithigollawa
6 Kahatagasdigiliya
7 Kalawewa
8 Maha Illuppallama
9 Maradhankadawela
10 Nachchaduwa
11 Nochchiyagama
12 Padawiya
13 Sungilikandharawa
14 Tambuththegama

(f) The use of a single set of 75% probability rainfall values **(see Table 3)** for the design of tanks in the entire NCP may lead either to the underestimation or overestimation of the available catchment yield. Thus if the 75% rainfall values for the DLI region are used for a tank in the NE part, the rainfall is underestimated by 28% and if used for the SW part, the rainfall is overestimated by 13%.

Table 3: 75% Probability Rainfall for DLI Agro-ecological Region

Maha Season		Yala Season	
Month	Rain (in inches)	Month	Rain (in inches)
October	5.0 (129 mm)	April	5.0 (127 mm)
November	6.0 (152 mm)	May	2.0 (51 mm)
December	5.0 (127 mm)	June	0.5 (13 mm)
January	3.0 (76 mm)	July	0.0 (0 mm)
February	1.0 (25 mm)	August	0.5 (13 mm)
March	2.0 (51 mm)	September	1.0 (25 mm)
Total	22.0 (558 mm)	Total	9.0 (229 mm)
Rainfall Volume	22/12 x 640 = 1,173 acft	Rainfall Volume	9/12 x 640 = 480 acft

(g) Therefore, it is recommended to use the 75% probability rainfall values of the closest rain gauge station when a tank is considered for rehabilitation. Standard methods such as Theisson's Polygon Method may be used to divide the NCP to different design rainfall regions for this purpose.

PART II - CATCHMENT YIELD/RUNOFF ANALYSIS

Different Estimates of Catchment Inflow/RunOff

Accurate estimation of runoff generated by a given rainfall amount from a tank catchment is very vital for selection, planning, and design of irrigation tanks for rehabilitation. It is also important for post-rehabilitation operation of tanks. It is therefore, required to review the existing methods and recent research findings on the estimation of seasonal catchment yield (runoff), with a view to identify the most acceptable method for the task.

At present, the iso-yield curve method (Ponrajah, A.J.P., 1982) is the most widely used approach for the estimation of catchment runoff. The method is briefly described here for easy comprehension. It should be noted here that the terms 'catchment yield' and 'catchment runoff' carry the same meaning and those terms are used in the text interchangeably.

A.1 Iso-Yield Approach

a) The sequential steps of the method is as follows.

i. Find the topo coordinates and net catchment area of the tank.
Ex. Mahakiriibbewa tank F/5 (11.20 x 7.10), Catchment area - 0.80 sqmls.

ii. Locate the tank on the Iso-yield curve maps used by the Irrigation Department (Ref: Design of Small Head works for Small Catchments by A.J.P. Ponrajah, pp 6 -17)

iii. Read the specific yield for maha and yala separately using the iso-yield contours of the maps. Interpolate between the contours if necessary.
Ex. Maha - 500 acft/sqml and yala 60 acft/sqml.

. Read the 75 % probability rainfall for the appropriate agro-ecological region (DL 1 for NCP) and convert the rainfall to an equivalent runoff volume (for a catchment of 1 sqmls.). **(See Table 4).**

Table 4: 75% Probability Rainfall for DL1 Region (Maha Season)

Month	Rainfall inches (mm)	Month	Rainfall inches (mm)
October	5.0 (127 mm)	April	5.0 (127 mm)
November	6.0 (152 mm)	May	2.0 (51 mm)
December	5.0 (127 mm)	June	0.5 (13 mm)
January	3.0 (76 mm)	July	0.0 (0 mm)
February	1.0 (25 mm)	August	0.5 (13 mm)
March	2.0 (51 mm)	September	1.0 (25 mm)
Total	22.0 (558 mm)	Total	9.0 (229 mm)

Rainfall volume (Maha) = 22/12 x 640 = 1173 ac.ft
Rainfall volume (Yala) = 9/12 x 640 = 480 ac.ft

vi. Check whether the specific yield read from the iso-yield curve for yala and maha seasons is more than 35 % of the equivalent rainfall volume. If yes, take the actual catchment yield as 35 % of the rainfall volume. If not, take the estimated value. similarly, if the percentage is less than 7.5 %, take the catchment yield as 7.5 %. Thus the iso-yield approach assumes the same upper and lower limits of 35 % and 7.5 % of the rainfall as the effective catchment runoff for yala and maha seasons.

Ex. Percent estimated yield for maha = 500/1173 = 42%
But the percentage is more than 35 %.
Thus, the effective yield (maha) = 0.35 x 1173 = 410 acft/sqml

Percent estimated yield for yala = 60/480 = 12.5 %
This is within the specified limits
Thus, the effective yield (yala) = 60 acft/sqml

The above values are for a catchment area of 1 sqml. Therefore. if the catchment area is known (0.8 sqmls), then the yala and maha catchment yields can be computed.

vii. For water budgeting based tank operation studies, it is required to compute monthly values of catchment runoff. It is done by computing the monthly specific yield (yield factor) or yield per unit rainfall and by multiplying the monthly rainfall by that factor.

ex. Monthly sp. yield (yield factor) = 410/22 = 18.63 acft/sqml
Yield for month of October = 18.63 x 5 = 93.0 acft/sqmls

Compute catchment yield for the other months similarly.

b) It is seen that the entire NCP lies within the Maha iso-yield contours of 300 - 500 Ac.ft/Sq.mls. Thus, the maximum catchment yield in maha is 410 acft, once the upper limit of 35 % or a runoff coefficient of 0.35 is applied. The above illustration shows that when the iso-yield value for any tank catchment as read from the iso-yield contour map is higher than 410 Ac.ft/Sq.ml, the run off coefficient is 3.5% (0.35) and when it is less than 410 Ac.ft/Sq.ml, the runoff coefficient too proportionately reduces.

c) For example, if the value read is 325 Ac.ft/Sq.ml, then the corresponding runoff coefficient is (0.35 x 325)/400 or 28%(0.28). Similarly for Yala season, the entire NCP lies within the contour of 50-100 Ac.ft/Sq.mls. Thus, if the value obtained from iso-yield map is 70 Ac.ft/Sq.ml, the catchment runoff percentage (coefficient) is 70/480 or 14% (0.14). As the NCP lies within the iso-yield contours of 50-100, this method suggest catchment runoff percentages (coefficient) ranging from 10% (0.1) to 21% (0.21) for yala, depending on the location of the tank.

d) Thus, instead of following the entire computational procedure, one may simply apply a runoff coefficient of 0.35 to 75 % probability values to obtain catchment runoff in maha season. What is required is only to check whether the first value of iso-yield read from the map is less than 410.

e) Application of runoff coefficients, instead of the entire iso-yield computation procedure is a short-cut method for the runoff estimation for the NCP, if the iso-yield curve approach together with the 75% probability rainfall values for the DLI agro-ecological region are used. For the analysis that follow in this chapter, a runoff coefficient of 0.35 is applied to the 75 % rainfall probability values for convenience in computation and to enable comparison with other models of catchment runoff estimation suggested by various researchers.

Alternative runoff estimation models

Different runoff estimation models have been suggested by a number of research studies conducted in the NCP recently. The study results are reviewed below.

A.2. Mahakanumulla Cascade Study

A water balance study carried out at Maha Kanumulla cascade of the NCP during 1985 - 1989 (Dharmasena, 1991, Dharmasena, undated) found that a (tank) catchment absorbs a significant amount of rainfall for the initial soil saturation before it generates productive runoff. This pre-requisite was found to be 140 mm and 220 mm for yala and maha seasons respectively for one of the minor tank catchment (Paindikulama) of the cascade. According to the study, once the initial saturation requirement has been met, the total subsequent seasonal percentage runoff generated from the saturated catchment was about 20 % and 15 % of total maha and yala seasonal rainfall respectively. These estimates correspond to runoff coefficients of 0.2 and 0.15 respectively.

The study suggested the following rainfall-runoff relationships for the Paindikulama tank catchment.

Yala season: Runoff = 0.15 x Rainfall - 21

Maha season: Runoff = 0.20 x Rainfall - 44

(Rainfall and Runoff are in mm)

A.3 Walagambahuwa Tank Study

A separate study (Somasiri, 1979) carried out in an another tank (Walagambahuwa tank) of the same cascade concluded that percent seasonal runoff in two consecutive maha seasons (76/77 maha and 77/78 maha) were 5% and 25% of the seasonal rainfall respectively, the higher value being in the year of comparatively higher seasonal rainfall in 77/78 maha season (1006 mm against 806 mm in 76/77 maha). However, the seasonal runoff percentage did not exceed 3% in the two consecutive yala seasons (yala 77 and 78). The results are shown in **Table 5.**

Table 5: Walgambahuwewa Catchment Water Balance Study (Somasiri, 1979). Rainfall Runoff Relations

Crop Season	Seasonal Rainfall mm	Seasonal Runoff mm	Runoff percentage %	Total Seasonal inflow to tank	Direct Rain-fall on tankbed %	Catchment run off to tank %
1976/77 Maha	804	48.3	6%	83.9	35%	65%
1977 Yala	510	13.4	2.6%	35.4	67%	33%
1977/78 Maha	1006	236.1	23%	361.2	35%	65%
1978 Yala	277	7.4	2.7%	29.0	75%	25%

The interesting finding here is the significant contribution to tank storage during a season by direct rainfall falling during the season on tank water spread and tank bed, which is usually not taken into account when iso-yield method is used for tank operation studies.

A.4 Tirappane Tank Cascade Study

A recent study conducted by IIMI, (Ithakura et al, 1994) in Tirappane cascade in the NCP, observed the percentage runoff (runoff coefficients) generated from rainfall in the four seasons. The findings are tabulated in **Table 6**.

Table 6: Tirapanne Tank Cascade Study (J. Itakura et.al, 1994). Percentage Runoff Coefficients

Season	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5
1991/92 Maha	34%	31%	25%%	28%	32%
1992 Yala	10%	12%	5%	12%	13%
1992/93 Maha	9%	18%	7%	13%	15%
1993 Yala	3%	5%	1%	5%	8%

Note: Tank 1 - Vendarankulama tank
Tank 2 - Bulankulama
Tank 3 - Meegassagama tank
Tank 4 - Alisthana tank
Tank 5 - Tirappane tank

For the two successive maha seasons, the average runoff percentage was 30 % and 12 % respectively, and for the two successive yala seasons 10 % and 4.5 % respectively. These values correspond to runoff coefficients of 0.3 and 0.12 for maha and 0.1 and 0.045 for yala.

A.5 Nachchaduwa and Huruluwewa Catchment Management Study

A catchment and water management study conducted in Huruluwewa and Nachchaduwa catchment areas (Somasiri 1992) of the NCP during 1985-1991 gave interesting results. It reported that runoff generated from chena is in the range of 20-25% of the total Maha rainfall, forest and scrub 2%, and teak plantations in the region of 10-15%. It also reported that the catchment runoff from forest, abandoned chena and scrub jungle lands appear to be very similar and those lands would generate runoff only under very high rainfall conditions and after a high soil saturation requirement has been met. This shows theoretically, the importance of evaluating the land use pattern of a catchment as a basis for estimating the catchment yield. As a major portion of the tank catchments of the NÇP consist of chena lands, as revealed by the rapid appraisal survey conducted for the IFAD study, it can be reasonably assumed that the runoff percentage from the saturated catchment is in the range of 20-25%. This study found that the initial soil saturation requirement is 90 mm for the Maha season.

Analysis and Comparison of Different Models

Rainfall and Catchment Runoff

A comparison of different estimates of catchment runoff coefficient and catchment runoff by the methods described above for four tanks studied are shown in **Tables 7 and 8** (Hiriwaduna and Punchikulama tanks for yala season) and **Figure 9** (Anduketiyawa and Bellankadawala tanks for maha season). The comparison shows that catchment runoff computed by the conventional Iso-yield model and Mahakanumulla models give the highest and lowest estimates. The ratio between these two estimates for maha season is as high as 3.0.

Table 7: Different Estimates of Catchment Runoff for Yala Season

Hiriwadunna Tank - Catchment Area 4.00 Sq. miles

Month	75% Probability Rainfall (DL1)	ISO-yield Curve Approach		Maha Kanumulla Study		Tirappane Study		Walagambahuwa Study	
	mm	Runoff co-eff.	mm	Runoff co-eff	mm	Runoff co-eff	mm	Runoff co-eff	mm
April	127	0.10	51		0	0.10	51	0.03	15
May	51	0.10	20		23	0.10	20	0.03	6
June	13	0.10	5	0.15	8	0.10	5	0.03	2
July	0	0.10	0	0.15	0	0.10	0	0.03	0
August	13	0.10	5	0.15	8	0.10	5	0.03	2
September	25	0.10	10	0.15	15	0.10	10	0.03	3
Total	229		91		54		51		28

Table 8: Different Estimates of Catchment Runoff for Yala Season

Punchikulama Tank - Catchment Area 1.60 Sq. miles

Month	75% Probability Rainfall (DL1)	ISO-yield Curve Approach		Maha Kanumulla Study		Tirappane Study		Walagambahuwa Study	
	mm	Runoff co-eff.	mm	Runoff co-eff	mm	Runoff co-eff	mm	Runoff co-eff	mm
April	127	0.10	20		0	0.10	20	0.03	6
May	51	0.10	8		9	0.10	8	0.03	2
June	13	0.10	2	0.15	3	0.10	2	0.03	1
July	0	0.10	0	0.15	0	0.10	0	0.03	0
August	13	0.10	2	0.15	3	0.10	2	0.03	1
September	25	0.10	4	0.15	6	0.10	4	0.03	1
Total	229		36		21		36		11

Table 9: Tirapanne Tank Cascade Study (J. Itakura et.al. 1993). Proportions of Catchment Runoff, Direct Rainfall and Drainage Return Flows.

Season	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5
1991/92 Maha:					
a	86	55	56	49.5	48
b	14	26	15	15	13
c	00	19	29	35.5	39
1992 Yala:					
a	80	74	60	72	64
b	20	26	40	28	36
c	00	00	00	00	00
1992/93 Maha:					
a	75	74	61	61	64
b	25	21	21	23	17
c	00	05	18	16	19
1993 Yala					
a	62	80	49*	60	67
b	38	20	51	40	33
c	00	00	00	00	00
Average Maha:					
a	80.5	64.5	58.5	55.5	56
b	19.5	23.5	18	19	15
c	00	12	23.5	25.5	29
Average Yala:					
a	71	77	54.5	66	65.5
b	19	23	45.5	34	34.5
c	00	00	00	00	00

Note: Tank 1 - Vendarankulama tank   Tank 2 - Bulankulama
Tank 3 - Meegassagama tank   Tank 4 - Alisthana tank
Tank 5 - Tirappane tank

a - catchment runoff
b - direct rainfall on tank
c - drainage return flows from upstream paddy area
* - (runoff is less than direct rainfall, may be an outlier.)
For tank 1, which is the uppermost tank in the cascade, no drainage return flow.

The comparison of the 75% probability rainfall values for the DL 1 region (**Figure 8 and Table 2**) well agree with the values for Kalawewa, Kahatagasdigiliya, Habarana, Maha Illupalama and Maradankadawala areas. But, the 75% probability rainfall for Anuradhapura and Nachchaduwa are lesser while for Horowpathana and Kabethigollewa are higher than the DLI values. This trend is observed but he Nachchaduwa and Huruluwewa catchment study (Somasiri 1992) too. The study reported that seasonal average rainfall decreases in the general direction of North-East to South-West. Thus, one may expect a higher total seasonal catchment runoff from the tanks in the North-Eastern part of the NCP and lower values around Anuradhapura and Nachchaduwa area.

Direct Rainfall on the Tank and Drainage Return Flow During Season

The Mahakanumulla study reported that there is a distinct contribution to tank storage by direct rainfall falling over the tank bed and its water spread area. It found that in maha, 70 % of the tank storage was contributed by catchment runoff, while the balance 30 % by direct rainfall on tank. The relative proportions were 40% and 60 % respectively in yala season.

The Walagambahuwa study reported that, on average, two thirds (67 %) of the tank storage was resulted from catchment runoff and the other one third (33 %) from direct rainfall on the tank water spread and bed in maha season (**Table 5**). But in yala, on average, only 29 % of the tank storage resulted from catchment runoff and the balance 71 % by the direct rainfall.

The Tirappane cascade study separated the total inflow to tank (plus spillage if it occurs) into three components. i.e. a) inflow from the catchment, b) direct rainfall on tank bed, and c) drainage return flows from the command area of the upstream tank of the cascade.

The percentage contributions observed are tabulated in **Table 9** above. It is to be noted that drainage return flow from the upstream paddy lands is available only if the upper areas are cultivated in maha. Thus, this component may or may not be available to the tank in every maha season.

The same data are used to compute the relative proportions of catchment runoff and direct rainfall on the tank, assuming the drainage return flow contribution is zero. This will enable comparison of these proportions with the values observed by other studies. The results are tabulated in **Table 10**.

It is seen from Tables 9 and 10 that the relative proportions of total seasonal contribution to tank in maha season for the tanks differ that from the upper most tank (Vendarankulama) of the cascade. Thus, for computing average values, the upper most tank was not considered. Thus, the average proportions of catchment runoff, direct rainfall and drainage return flow for maha are found to be 59%, 19% and 22% respectively. For yala, the proportions are, 67%, 33% and 0% respectively.

When there is no drainage return flow from the upstream paddy areas, the relative proportion of catchment runoff and direct rainfall for maha are found to be 75% and 25 % respectively. For yala, the proportions are, 67% and 33% respectively.

Comparing the results of the three studies it can be concluded that on average, the 70 % of the total seasonal tank storage is supplied by catchment runoff, while the balance 30% by the direct rainfall on tank bed during maha. But for yala, the findings of Mahakanumulla and Walagambahuwa studies give average values of 35 % from catchment runoff and 65 % from direct rainfall. But the values of Tirappane study are 67 % from catchment runoff and 33% from direct rainfall, which do not agree with the results from the other two studies. More research studies are required to refine these values. However, the values for maha may be used for a quick evaluation of total seasonal yield in preliminary appraisals and for tank operation studies.

Table 10: Tirapanne Tank Cascade Study (J. Itakura et.al, 1991) Proportions of Catchment runoff and Direct Rainfall

Season	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5
1991/92 Maha					
a	86	67	78	76	79
b	14	33	22	24	21
1992 Yala					
a	80	74	60	72	64
b	20	26	40	28	36
1992/93 Maha					
a	75	75	74	72	79
b	25	25	26	28	21
1993 Yala					
a	62	80	49	60	67
b	38	20	51	40	33
Average Maha					
a	80.5	71	76	74	79
b	19.5	29	24	31	21
Average Yala					
a	71	77	54.5	66	65.5
b	19	23	45.5	39	34.5

Note: Tank 1 - Vendarankulama tank   Tank 2 - Bulankulama
Tank 3 - Meegassagama tank   Tank 4 - Alisthana tank
Tank 5 - Tirappane tank
a - catchment runoff   b - direct rainfall on tank

For the two maha seasons, the study found drainage coefficients of 27.6% and 34.6%, leading to an average of 31%. No drainage return flows take place in yala and hence drainage coefficient is zero.

Summary of findings and major recommendations

(a) Two models (Mahakanumulla, Nachchaduwa and Huruluwewa study) suggests that no runoff is generated with the seasonal rainfall unless the pre-saturation requirement of catchment soils have been adequately met. The other models including the standard iso-yield curve approach does not take the initial pre-saturation requirement or the initial loss into account in the runoff computations.

(b) There is a difference between the free-saturation requirement suggested by the two models. Mahakanumulla study suggests that unless there is a cumulative rainfall of 140 mm for Yala and 220 mm for Maha, no runoff is generated, while the Nachchaduwa and Huruluwewa study suggests a pre-saturation requirement formula of 90 mm in Maha season. The value for Yala is acceptable while the actual pre-saturation requirement appear to lie in between 90 and 220 mm.

(c) It is, therefore, suggested that unless more reliable and field verified data are available a pre-saturation requirement of 200 mm is set apart from the initial cumulative seasonal rainfall in the catchment runoff estimation for minor tank rehabilitation design and operation studies.

() The runoff coefficient used to convert rainfall into runoff from catchment by the different models compare as follows:

Model	Runoff Coefficient	
	Yala	Maha*
Iso-yield	0.10 - 0.20	0.25 - 0.35
Mahakanumulla*	0.15	0.20
Walagambahuwa	0.03	0.05 - 0.25
Tirappane	0.04 - 0.10	0.12 - 0.30
Nachchaduwa* and Huruluwewa	-	0.20 - 0.35

* After meeting the pre-saturation requirements.

This show that the catchment runoff estimated by the iso-yield approach is always on the higher side for both Yala and Maha season and the runoff coefficients suggested by all the other models lead to lower catchment runoff values. There is a general opinion of the farmers in the NCP that tanks do not fill in Maha sufficient enough to do a successful cultivation. The spilling index (number of years spilled during the last 10 years) and the filling index (number of years the tank filled to a desired level or 75% or 100% during the last 10 years) shown in **Table 11** for 15 tanks studied during the rapid field appraisal survey for the current study reveals this fact.

(e) The above comparison in (d) shows that the iso-yield curve approach overestimate the catchment runoff. When iso-yield curve approach is used together with the 75% probability rainfall values for DLI region without considering the spatial variability of rainfall, the degree of error tend to be higher.

(f) **Figure 9** illustrates the degree of variation of catchment runoff computed for two tanks (Anduketiyawa tank: catchment area 0.6 sq.mls and Bellankadawala tank: catchment area 2.8 sq.mls) using different catchment runoff estimation models. It is seen that for the same tank, the ratio between the most optimistic value (iso-yield model) and the most conservative value (Mahakanumulla model) is as high as 3.0 for a unit tank catchment. Therefore, selection of the most representative runoff coefficient is very vital.

(g) As the catchment area of a tank increases, the estimated monthly tank inflow values too tend to increase in direct proportion and may result in exaggerated monthly runoff values unless the correct runoff coefficient is used. If such exaggerated monthly and seasonal runoff values, are used for tank operation studies to determine the potential cropping intensity, the expected results may be highly misleading. If a decision is taken to invest for tank rehabilitation by judging the potential cropping intensity computed on the above basis, the consequences would be obvious. This may be partly the case with the tanks rehabilitated in the NCP by previous rehabilitation programmes, as revealed by a number of post-rehabilitation studies (see reference) and the findings of the rapid field appraisal study conducted for this study.

(h) In view of the above situation, it is essential to select the most acceptable catchment runoff estimation model. It is not possible to recommend one single model for this purpose at this point of time as no adequate research information is available to arrive at conclusive values. Therefore, it is recommended that a runoff coefficient of 0.30, instead of 0.35 be used with 75% probability rainfall measured at nearest rainfall station to the tank, deducted with a pre-saturation requirement of 200 mm, until more conclusive data would be available in the future.

Drainage Return Flow and Direct Rainfall

(a) The contribution by drainage return flow from the upstream areas cultivated and direct rainfall falling to tank bed during the season are not taken into consideration for tank water balance studies at present. Thus, those two parameters should be considered.

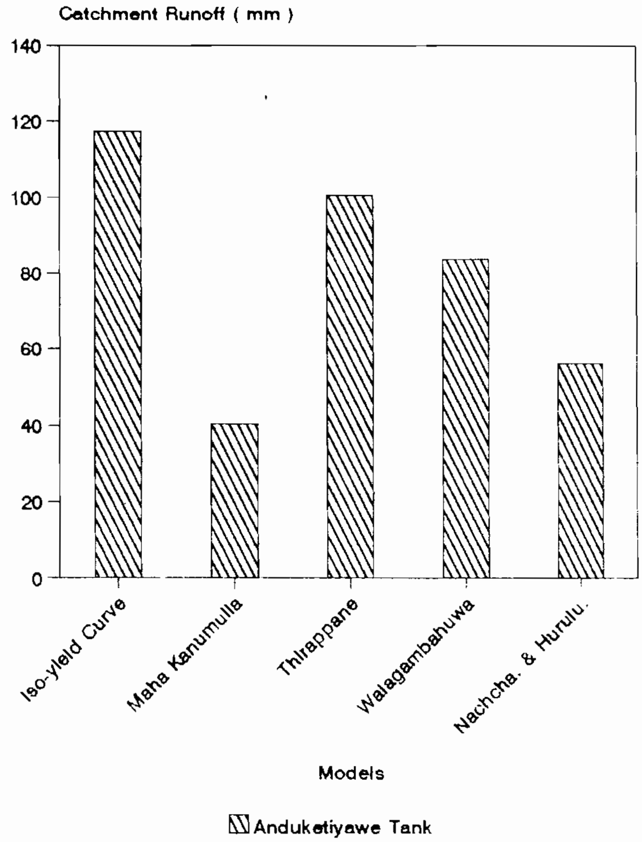
Table 11

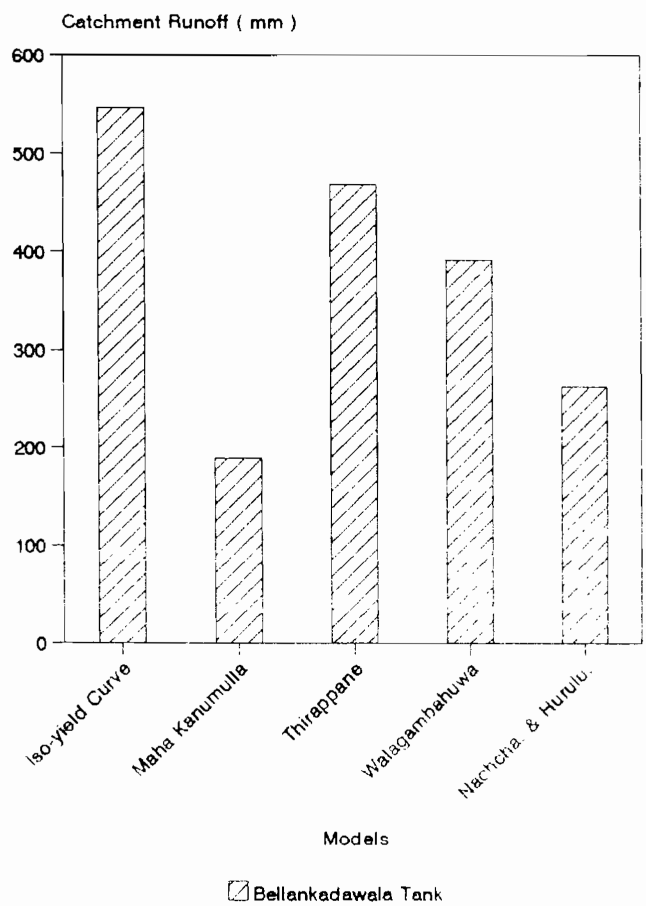
COMPARISON OF CATCHMENT, TANK, COMMAND PARAMETERS WITH SUCCESS OF FILLING AND CROPPING

NAME OF TANK	CATCH. AREA (Sqmls)	FULL STORAGE (Acft)	COMMAND AREA (Reported) (Acres)	COMMAND AREA (Actual) (Acres)	CATCH. STORAGE RATIO (acres/acft)	CATCH. STORAGE RATIO (ha/ha.m)	CATCH. COMMAND RATIO	STORAGE COMMAND RATIO (Acft/Ac)	SPILLING INDEX	FILLING INDEX(F) (100%<F >75%)	FILLING INDEX(F) (75%<F >50%)	FILLING INDEX(F) (F<50%)	CROPPING INTENSITY (Maha)
Hiriwadunna	4.00	536	135	110	4.78	15.67	23.27	4.87	1.0	0.0	0.0	0.0	0.67
Punchikulama	1.60	445	180	110	2.30	7.55	9.31	4.05	0.2	0.1	0.3	0.4	0.13
Sivalakulama	0.92	492	145	135	1.20	3.93	4.36	3.64	0.2	0.3	0.5	0.0	0.3
Maradankadawala	1.59	244	162	100	4.17	13.68	10.18	2.44	0.4	0.3	0.3	0.0	0.3
Paluketuwewa	1.00	590	190	190	1.08	3.56	3.37	3.11	0.3	0.2	0.2	0.5	0.34
Bellankadawala	2.80	620	115	115	2.89	9.48	15.58	5.39	0.4	0.3	0.3	0.0	0.96
Kiriibewa	0.80	302	100	103	1.70	5.56	4.97	2.93	0.2	0.8	0.0	0.0	0.73
Nelugollakada	1.88	315	148	148	3.82	12.53	8.13	2.13	0.8	0.2	0.0	0.0	0.63
Elapathgama	0.80	–	87	87	–	0.00	5.89	0.00	0.1	0.0	0.0	0.9	0
Anduketiyawa	0.60	152	123	62	2.53	8.29	6.19	2.45	0.2	0.8	0.0	0.0	0.71
Vendarankulam	0.75	178	45	45	2.69	8.82	10.67	3.95	0.5	0.2	0.2	0.1	0.72
Bulankulama	0.25	81	45	42	1.97	6.46	3.80	1.93	0.5	0.5	0.0	0.0	0.75
Meegassagama	1.37	292	80	80	3.00	9.84	10.96	3.65	1.0	0.0	0.0	0.0	0.75
Alisthana	1.43	470	96	96	1.94	6.36	9.53	4.90	0.4	0.6	0.0	0.0	0.80
Thirappane	1.73	640	85	85	1.73	5.67	13.03	7.53	0.2	0.8	0.0	0.0	1.00

Figure 9 Catchment Run off Estimation by different models for ' Maha '

(Based on 75% Probability Rainfall for DL 1 region)





(b) The attached sample shows the results of the simulation developed for Bellankadawala tank of the NCP **(refer to Table 12 of Annexure 4)**. The simulation model used herein was developed for this study. Although, it can be used as it is for sensitivity analysis of the Cropping intensity for various hydrological models, technical and managerial improvements, it need to be further improved for more capacity and capabilities.

(c) Those results show basically the sensitivity of cropped area for the drainage return flow and direct rainfall. Drainage return flow from the upstream paddy areas have been assumed as 20% of the total field irrigation requirements applied there. Yield calculation model number 1 under DLI of the tabulation of simulation study sample attached herein, which corresponds to the standard method used by the Irrigation Department, shows the sensitivity of drainage return flow on cropping intensity. The results for that particular trial run for Bellankadawala tank shows that the probable command area increases by about 16% when both direct rainfall and drainage return flows are taken into account. Thus a drainage return flow coefficient of 0.2 should be assumed.

ANNEXURE 4

SIMULATION MODELLING OF TANK CASCADES AND INDIVIDUAL TANKS

Once a tank cascade is selected for further analysis based on maha cropping intensity (CI) and other parameters explained in Section 5.2 of this report, the next step is to evaluate the potential CI of each tank of the cascade.

The actual or realized CI of a tank or tanks of a cascade in maha season is the basis for characterizing individual tanks and finally the hydrological potential of the tank cascade. It is used together with other parameters (ex. CCA/WA and COA/WA ratios) to characterize individual tanks and identify the nature of rehabilitation work that should be undertaken for a given tank (see Section 5.3).

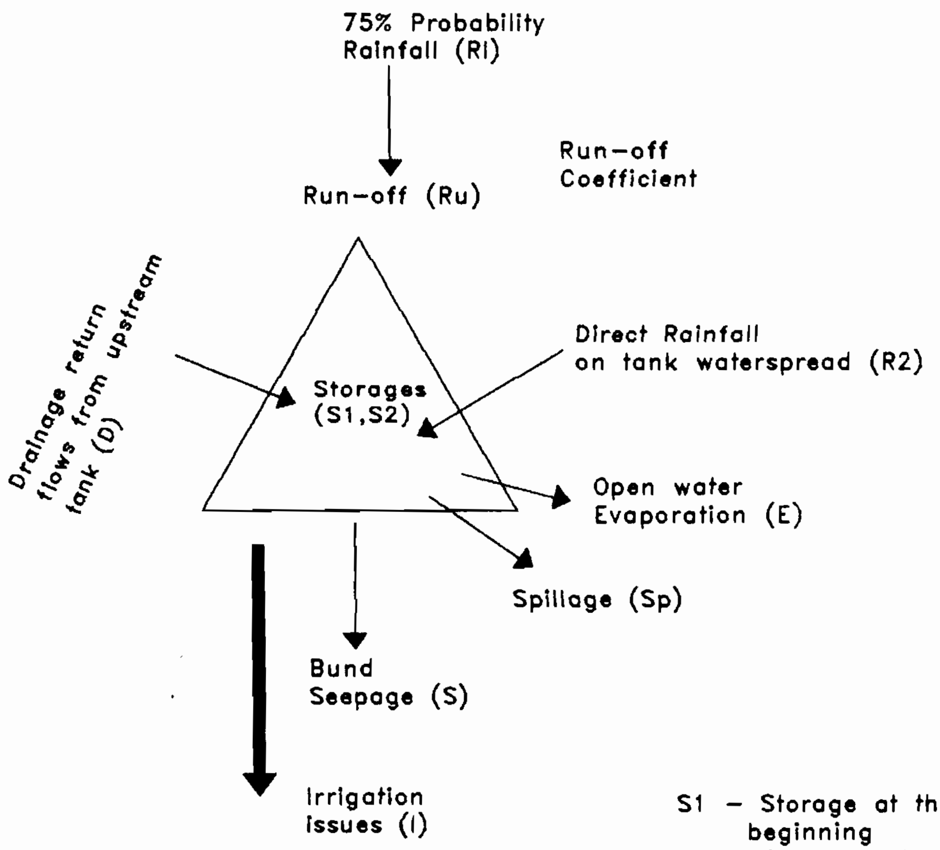
Once, the primary nature of rehabilitation is identified, it is required to identify the most cost-effective combination of hydrological, technical and managerial improvements to increase its CI. The simulation model is used for this purpose.

The principle of the proposed simulation model is that it simulates potential cropping intensity for a given tank for a given intervention and/or a set of interventions. The conceptual diagram for the proposed simulation model is shown in **Figure 10**. The model will simulate the probable cropping intensity (and probable command area) that can be cultivated under the tank under the given hydrologic conditions, proportion of well and poorly drained soils in the command, commencement date of maha cultivation, cropping pattern and the efficiency of the irrigation distribution system.

As given in the conceptual diagram, the primary model inputs are:

* catchment area of the tank;
* monthly 75% probability rainfall values appropriate for the location of the tank cascade;
* runoff coefficients to enable conversion of rainfall to runoff (inflow to tank);
* monthly open water evaporation rates and tank loss rates;
* Direct rainfall on tank bed during a cultivation season; and
* percentage rate of drainage return flow from the upstream paddy cultivated areas.

Figure 10 - Conceptual Model for Tank and Tank Cascade Simulation



S1 – Storage at the beginning of the month

S2 – Storage at the end of the month

For a time period of one month

$$S1+D+Ru+R2 = S2+E+Sp+S+I$$

For an assumed cropping pattern, cropping intensity (CI), soil proportions in the command, commencement date of cultivation, extents grown with rice and non-rice crops, "I" can be estimated.

Run the model by balancing tank water storages monthly for different I values until the most acceptable CI is found by simulation.

The evaluation of all of the above parameters have been explained in **Annexure 3.**

The variable model inputs are as follows:

* depth-area-capacity relationship for the tank to enable computation of direct rainfall on tank during the season, open water evaporation and losses from the tank during the season;

* cropping pattern;

* proportion of well and poorly drained soils in the command;

* existing command area;

* date of commencement of maha season;

* Bund seepage losses;

* conveyance efficiency of the distribution system;

* application efficiency of the on-farm layout;

The model will carry out a water budgeting on monthly basis and compute the maximum command area that can be brought under cultivation in maha for a given set of variable input parameters and for different cropping scenarios. In other words, the model will test the sensitivity of the CI (or the probable command area) for technical and managerial interventions fed into the model in terms of the above variable input parameters.

Some of model applications are illustrated below briefly.

(a) the model can be used to simulate the potential benefit of rehabilitation once after evaluating the causes for the present gap between the potential and realized cropping intensity of any tank. For an example, if the reason for poor cropping intensity is bund leakage and poor irrigation system which makes water shortage for cropping, then the intervention is to improve the physical irrigation system and to arrest bund leakage. The model will simulate the area that would be potentially possible to bring under cultivation in a typical maha season, if the bund leakage and poor distribution system are arrested. The variable inputs in this case are bund loss factor, conveyance efficiency and application efficiency.

(b) On the other hand, if the reason for poor cropping intensity is socio-economic, say that farmers are reluctant to cultivate because of difficulty in water management, crop care, and low profits associated with fragmented and dispersed parcels of lands, then the intervention may be to go for land consolidation. The model would take into account the improved water application efficiency and less land preparation water requirements to simulate the potential cropping intensity after the land consolidation has been done. The model will also simulate the influence of dug wells in the command on the cropping intensity.

(c) If a tank having a higher CCA/WA ratio (> 7.5) is considered for raising its full supply level to undertake additional command area under the tank, the model should be run to assess the impact of the proposed tank improvements on the hydrology of the tanks downstream of the cascade and to evaluate the probable command area that can be brought under cultivation after increasing tank capacity.

Thus, it is recommended a simulation model should be developed to:

- simulate potential cropping intensity of tanks;

- identify the influence on cropping intensity by each individual and combinations of physical, agronomic, socio-economic and organizational interventions of rehabilitation.

- select what rehabilitation interventions are more vital to improve the cropping intensity.

- evaluate the potential benefits of the selected interventions of rehabilitation in terms of increased cultivated area, increased crop yields, reduced crop failures etc.

- compute cost-benefit ratio and internal rate of return to justify the tank for selecting for rehabilitation.

A simulation model having a few of the above desired feature was developed as a part of the consultancy. The model was run for 10 sample tanks studied by the rapid field appraisal survey for this consultancy. The computer output of one sample tank (Bellankadawala Tank) is annexed as **Table 12** for illustrating the purpose and advantages of the proposed simulation model. **Table 12** tabulates the sensitivity of probable command area for the sample tank for different: (i) catchment runoff estimation models; (ii) catchment runoff coefficients; (iii) cropping patterns; and (iv) commencement dates for maha season.

It has to be noted that the model needs a number of refinements and improvements to have its full advantage and benefits, because it was not possible to develop it fully during the short term period available for this consultancy.

Bellankadawela Tank

Optimization Analysis Report
Irrigable Maximum Command Area (Acres)

R/F Pattern	Yield Calculation	Crop Pattern	01/10/94	15/10/94	01/11/94	15/11/94	01/12/94	15/12/94
			Start Date of Cultivation					
DL1	1	100% Paddy	70.00	100.00	100.00	100.00	90.00	90.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	63.00	99.00	90.00	99.00	90.00	90.00
		10% Chille	7.00	11.00	10.00	11.00	10.00	10.00
	2	100% Paddy	0.00	0.00	30.00	40.00	50.00	50.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	0.00	0.00	27.00	36.00	45.00	54.00
		10% Chille	0.00	0.00	3.00	4.00	5.00	6.00
	4	100% Paddy	70.00	100.00	90.00	100.00	80.00	90.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	63.00	99.00	81.00	90.00	81.00	81.00
		10% Chille	7.00	11.00	9.00	10.00	9.00	9.00
	5	100% Paddy	60.00	80.00	80.00	90.00	80.00	80.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	54.00	81.00	81.00	81.00	72.00	81.00
		10% Chille	6.00	9.00	9.00	9.00	8.00	9.00
	6	100% Paddy	10.00	20.00	50.00	60.00	50.00	50.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	9.00	18.00	45.00	54.00	45.00	45.00
		10% Chille	1.00	2.00	5.00	6.00	5.00	5.00
HORO	1	100% Paddy	70.00	110.00	120.00	130.00	100.00	110.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	72.00	108.00	108.00	117.00	99.00	108.00
		10% Chille	8.00	12.00	12.00	13.00	11.00	12.00
	2	100% Paddy	0.00	0.00	60.00	70.00	60.00	70.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	0.00	0.00	54.00	63.00	63.00	63.00
		10% Chille	0.00	0.00	6.00	7.00	7.00	7.00
	4	100% Paddy	70.00	110.00	110.00	120.00	100.00	100.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	72.00	108.00	99.00	108.00	90.00	99.00
		10% Chille	8.00	12.00	11.00	12.00	10.00	11.00
	5	100% Paddy	60.00	90.00	100.00	110.00	90.00	90.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	63.00	90.00	90.00	99.00	81.00	90.00
		10% Chille	7.00	10.00	10.00	11.00	9.00	10.00
	6	100% Paddy	20.00	20.00	60.00	70.00	60.00	60.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	18.00	27.00	54.00	63.00	54.00	54.00
		10% Chille	2.00	3.00	6.00	7.00	6.00	6.00

Table 12 Sensitivity of Cropping Intensity (Probable Command Area)

Table 12 Contd.....)

NACH	1	100% Paddy	80.00	80.00	70.00	70.00	60.00	70.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	72.00	72.00	63.00	72.00	63.00	63.00
		10% Chille	8.00	8.00	7.00	8.00	7.00	7.00
	2	100% Paddy	0.00	0.00	20.00	30.00	30.00	40.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	0.00	0.00	27.00	36.00	36.00	36.00
		10% Chille	0.00	0.00	3.00	4.00	4.00	4.00
	4	100% Paddy	70.00	70.00	60.00	70.00	60.00	60.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	72.00	63.00	54.00	63.00	54.00	54.00
		10% Chille	8.00	7.00	6.00	7.00	6.00	6.00
	5	100% Paddy	70.00	70.00	60.00	60.00	50.00	60.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	63.00	63.00	54.00	63.00	54.00	54.00
		10% Chille	7.00	7.00	6.00	7.00	6.00	6.00
	6	100% Paddy	20.00	30.00	30.00	40.00	30.00	30.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	18.00	27.00	27.00	36.00	27.00	27.00
		10% Chille	2.00	3.00	3.00	4.00	3.00	3.00

Notes:

Rainfall Patterns : DL1 - 75% probability rainfall for DL1 region
HORO - -do- for Horowpothana
NACH - -do- for Nachchaduwa

Yield Calculation Methods : 1 - ID Standard
2 - Mahakanamulla Study
4 - Tirappane Study
5 - Walagambahuwa Study
6 - Nachchaduwa & Huruluwewa Study

Direct Rainfall Contribution : Considered
Drainage Contribution : Considered
Effective Rainfall (on farm) : Considered

27/10/94/ROSES/2.00/IIMI/ESC

Reservoir Operation Simulation (Extended) System
Version 2.00 - October 1994

Operation Manual

October 1994

Reservoir Operation Simulation (Extended) System
Version 2.00 - October 1994

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October 1994

1.0 General Overview

The program Reservoir Operation Simulation (extended) System (ROSES) was developed in December 1993 under a contract by Expert Systems Consultants for Sri Lanka Field Operations Division (SLFO) of the International Irrigation Management Institute (IIMI). It was originally used by the client for operation and control of reservoir system under Lunugamwehera Reservoir Scheme.

The version 2.0 of the program was developed as a modified version of the original program for water budgeting purposes of tank systems in North Central Province (NCP) dry zone. The modification was undertaken by the ESC and completed in 10 days. This version of the program can be used as an assistance tool for optimization studies of reservoir systems. The software model is very user-friendly, easy to use and flexible. It allows the user to change parameters and input data very easily through a comprehensively organized menu system. The results are represented on screen graphically to help a what-if type optimization analysis. Results as well as input and parametric data can be taken as hard copy print outs.

One important feature of this program is that it is capable to handle different methodologies adopted by different organizations and individuals based on research level findings on operational parameters of reservoirs such as inflows, losses, irrigation demands etc. The choice of the methodology of calculations is left to the user.

2.0 Hardware Requirements

An IBM or compatible personal computer is required with following minimum configuration.

DOS 3.0 or later
Intel 80286 or later
640 KB RAM minimum
Hard disk with about 2MB free space
Color monitor with CGA,EGA,VGA,SVGA display adaptor
3.5" diskette drive

A suitable printer should be connected to the computer through LPT1 printer port for printing outputs.

3.0 Technical Background of the Software System

3.1 General

The software system ROSES 2.00 is a powerful analytical tool for water resources specialists to carry out optimization analysis of reservoir systems. The most economical usage of tank water for supplying the demand of cultivation in the command area under the tank while accounting for various losses in application, seepage and percolation is the main objective of the program. The impact of the upstream reservoir is allowed for and as a result the drainage flow into the tank from upstream command area is calculated.

Cascade type operation of reservoirs is considered where the input to the down stream reservoir from US reservoir is considered only as drainage. The supply canal inflows or contribution from spill of US reservoir is not considered in this version.

3.2 Catchment Inflow (Yield)

The main inflow to a reservoir is the catchment yield. In calculating the catchment yield four different methodologies adopted by the researchers is incorporated. These four methodologies are;

1. Irrigation Department methodology based on the research report 'Design of irrigation headwork for small catchments' by Mr. A.J.P. Ponrajah.
2. Mahakanamulla Research findings of Department of agriculture - Mahailuppallama.
3. DANIDA study (regression model)
4. Itakura's cascade water management study (Thirappane study)

The following steps are involved in these different methods.

3.2.1 Irrigation Department Standard Method

i) Find the topo coordinates and net catchment area of the tank. Ex. Mahakiribbewa Tank F/5 (11.20 x 7.10), catchment area - 0.80 sqmls.

ii) Locate the tank on the iso-yield curve maps used by the irrigation department (ref: design of headworks for small catchments by A.J.P. Ponrajah, pp 6- 17)

iii) Read specific yield for Maha and Yala separately using the iso-yield contours of the maps. Interpolate between the contours if necessary.
ex. Maha - 500 acft/sqmls and Yala - 60 acft/sqmls

iv) Estimate the Yala and Maha seasonal yield by multiplying the specific yield values from the catchment area.
ex. Maha - 400 acft and Yala 48 acft

v) Read the 75% probability rainfall for the appropriate agro-ecological region and convert the rainfall to a run-off volume.
ex. agro-geological region DL1
75% probability rainfall (inches)

October	5.0
November	6.0
December	5.0
January	3.0
February	1.0
March	2.0

Total	22.0

Rainfall Volume = 22/12 x 640 = 1,173 acft

vi) Check weather specific yield from the catchment is more than 35% of the rainfall volume. If Yes, take the actual catchment yield as 35% of the rainfall volume. If not, take the estimated value.

ex. Percentage of estimated yield = 500/1173 = 42%

Therefore, the estimated yield = 1173 x 0.35 acft = 410 acft

vii) For operation study, we need to compute monthly values of catchment yields. It is done by computing the monthly specific yield and by multiplying the monthly rainfall by the monthly specific yield.

Monthly specific yield = 410/22

= 18.63 acft/sqml

Yield for month of October= 18.63 x 5

= 93.0 acft

Compute catchment yield for the other months similarly.

Note:

Estimate the catchment yield as explained above in (i) and (ii). Take the effective yield as 70% of the estimated yield. assuming a duty of 3 acft/acre, divide the effective yield by 3 to have a first approximation of the probable command. Do not take the direct rainfall on the tank when you use this approach. Take drainage return flow from upstream paddy fields as 20%

3.2.2 Mahakanamulla Research Findings of the Agriculture Department, Mahailuppallama

i) Dr. Dharamsena's findings - Assume the following rainfall-runoff relationships.

if Ru - Runoff in mm and R - Rainfall in mm

then for maha season, Ru=0.20xR - 44

for yala season, Ru=0.15xR - 21

For the first trial take both 75% probability rainfall values for the DL1 agro-ecological region as obtained from the 'Design of headworks for small catchments by A.J.P. Ponrajah

Try out a separate trial using 75% probability rainfall values computed by us for the closest rainfall station. Names of the rainfall stations and the 75% rainfall probability values are provided.

Assume usual tank net loss (UNL), including evaporation, seepage and percolation as,

UNL = 1.31 ln S - 0.85, where UNL is the net loss in cubic meters/week and S is the tank storage in 100 cu.m.

When you do the operation study using this approach, take into account the direct rainfall on the tank and drainage return flows from the upstream as 20%.

3.2.3 Water balance study data for Yanoya basin obtained from DANIDA study.

Use the yearly data to develop relationships for run-off and evaporation as function of rainfall. Use regression modelling to develop relationships. Apply the developed relationships to monthly rainfall values. For the first set, take the 75% probability values for the region. For the second set, take the 75% probability rainfall values for the closest station.

ex.

Year	Rainfall (mm)	Evaporation (mm)	Runoff (mm)	Recharge (mm)
1971	1276	915	177	65
1972	1504	904	542	180
1973	1106	865	274	102
1974	1010	908	168	55
....	....	....	...	...

1989	1301	715	290	112

3.2.4 Ithakura's cascade water management study (Thirappane study)

This study gives the following relationships.
For Maha, catchment yield = 0.30 x catchment area x rainfall
For Yala, catchment yield = 0.12 x catchment area x rainfall

The drainage return flow from upstream paddy is 30% in Maha and 0% in Yala.

Total tank loss (evaporation, S&P from tankbed and bund) is taken as 4.7mm/day for Maha and 6mm/day for Yala for unit water spread area of the tank. [Take the water spread area and multiply by 4.7 mm/day to arrive at the tank loss for a day].

For this simulation, take both the 75% probability rainfall data for the region and computed values.

3.2.5 Walagambahuwa Study

In this method a runoff coefficient of 0.35 is used. No initial saturation is taken into account.

Runoff = 0.35 * Catchment Area * Rainfall

3.2.6 Nachchaduwa & Huruluwewa Study

In this method a runoff coefficient of 0.4 is assumed. Initial saturation is not considered.

Runoff = 0.4 * Catchment Area * Rainfall

3.3 Drainage Return Flow

The drainage return flow from US reservoir is taken as a percentage (ex. 20%) of US total crop water requirement for each month.

3.4 Direct Rainfall Contribution

The contribution from direct rainfall on reservoir is considered as a considerable input to the tank and it is calculated based on given probability rainfall in inches per unit water spread area.

3.5 Tank losses

The direct tank water loss is mainly due to two reasons.

1. Evaporation	:	This loss is calculated using evaporation coefficient for the month per unit water spread area.
2. Seepage/Percolation	:	This loss is calculated as a percentage of the tank storage.

(Ref. 'Design of irrigation headwork for small catchment' for details.)

3.6 Irrigation Demand

The irrigation demand from reservoir is the total water required to release to meet the actual crop water requirement for cultivations in the command area. The losses in application and conveyance are considered by using application and conveyance efficiencies. The effective rainfall is considered in calculation of actual water requirement on farm level. The methodology is described in the same book referenced above.

3.7 Excess/Deficiency

The excess water is spilled from the tank. In the model if the final tank balance is below the minimum draw down level of the reservoir a deficit is recorded setting the tank to MDL volume and deficit volume is calculated. When spill occurred the tank is set to spill level volume and excess is taken as spill volume.

3.8 Water Balance

The water balance equation can be expressed as follows.

Final Volume = Initial Volume + Inflow(Yield) + Drainage + Direct Rainfall - Seepage - Evaporation - Irrigation Demand

The spill volume is calculated if final volume is greater than spill volume. The deficit is calculated if final volume is below the MDL volume.

3.9 Sensitivity to command area and start date of cultivation

The crop water requirement for a certain month for a particular crop is related to the area cultivated and the date of start of cultivation. Therefore these two parameters are very important in carrying out optimization analysis. Therefore two parameters can be varied to find the optimum area and the date of start of cultivation of a certain crop. This is referred as the cropping pattern. The computer model is capable of handling any crop pattern to carry out sensitivity analysis to economize the utilization of tank storage.

3.10 Capabilities of the Program

This software system ROSES 2.00 can be used for

1. Carry out water balance studies for a given reservoir
2. Carrying out sensitivity analysis for different cropping patterns which consists of crop type, area cultivated, date of start of cultivation.
3. Designing irrigation headwork for small catchment reservoirs.
4. Deciding on the best cropping pattern and to schedule operation of reservoir outlets (releases) to suit the selected cropping pattern.
5. Deciding the maximum irrigable area of a given reservoir system.

3.1 Salient Features of the Software System ROSES 2.00

- Easy to use, menu driven
- Well organized menu system
- Convenient data entry screen
- Attractive user interface
- Graphical representation of results
- Easy saving/retrieving data
- Portability of data and results to other commercial software systems.

4.0 Operating instructions

4.1 How to start

4.1.1 Install software to hard disk

1. Create directory in hard disk

   eg. MD\ROSES2

2. Copy all the files in drive containing the ROSES 2.00 diskette

   eg. CD\ROSES2

   Copy A:*.* C:

4.1.2 Start and Running

1. Change directory to created directory

   CD\ROSES2

2. Type command CW at the DOS prompt

4.2 About the menus and screens

4.2.1 Main Menu

Main menu consists of following 7 options. This is a light bar menu system like in Lotus 123.

Input - To enter/edit input data

Analyse - To process the given data and to calculate results

Process - Not activated in this version

Outputs - To get hard copy print outs of input data, results and default parameters.

History - To maintain history file in which the results for different runs are recorded.

Defaults - To change default parameters.

Quit - To exit to DOS

4.2.2 Input Menu

This is a pop up box menu which contain the following options.

New - To enter the data related to a reservoir system for the first time

Modify - To modify the data entered.

Get - To retrieve the data from previously saved data file.

Save - To save the current system data to a disk file

Print - To print the data entered for checking purposes.

Quit - To exit from the menu

4.2.3 New/Modify Options

This option displays a pop-up box menu containing following options by which you can enter or modify data items for the current system. The new option clears any previously defined data items.

Reservoir Data

Reservoir Curve

Specific Yield

Rainfall Data

Crop pattern

Catchment coefficients

Crop water table

Evapo-transpiration

Evaporation coefficients

Seepage coefficient

Application efficiency

Conveyance efficiency

Regression model data

Quit

Reservoir Data	-	Reservoir Id, description, spill Level, Spill Volume, MDL Level, MDL Volume, Initial Level, Initial Volume, Reservoir curve type (F - formula/ D - Discrete point table)
Reservoir curve	-	if formula coefficients of formula for calculation of storage and water surface area as a function of height. Polynomial type and Linear type formula can be defined. Polynomial formula - A(h-h0)^B+C coefficients A,B,C,h0 Linear formula - A(h-h0)+B coefficients A,B,h0
Specific Yield	-	The specific yield for the region obtained from iso-yield curve.
R/F data	-	Table of probability rainfall figures for probabilities from 90%-50% for each month. The rainfall pattern could be saved in a disk file for use in the optimisation/sensitivity analysis. You will be prompted to enter a file name to save the rainfall pattern.

Crop pattern - Cropping pattern consisting of area and date of start of cultivation for different crops both up-stream and down-stream command areas. In defining the crop pattern the paddy can be given. There is one important thing to remember here. In calculating the crop water requirement for paddy it is treated little different from other crops. If the sarting date of cultivation is less than 15/11/94 the 135 days veriety is considered and otherwise the 105 days veriety is selected automatically. In crop pattern you just have to enter PADDY and in crop water table include both of these verieties as follows.

135 days veriety	- enter as PADDY
105 days veriety	- enter as PADDY/2

Catchment table - Table catchment coefficients for different catchment segments such as forest, shrubs, chenas etc.

Cropwater table - Table of crop factors and duration for 4 different periods of cultivation ie. Initial, development, mid, final

Evapo-transpiration Evapotraspiration coefficients table for each month.

Evap. coefficients Table of evaporation coefficients.

Seepage coefficient as a percentage of storage which accounts for both seepage and percolation losses

Application efficiency as a percentage

Conveyance efficiency as a percentage

Regression model data Table of year,rainfall,evaporation,runoff for each month if regression model method is used for yield calculation (for default yield calculation method = 3).

4.2.4 Get/Save Options

A file name is required in both of these options. The difault file name displayed is the current system identity with .DAT extension added. You can accept the default by pressing the enter key or change the file name.

Note : The default parameter settings also saved when the data is saved to disk file. Therefore when you retrieve them back remember to check defaults to verify correctness.

4.2.5 Print Option

All the data items defined in for the current system are printed to the printer connected to the computer. These prints can be checked for validity before doing processing.

Tip: At the prompt 'Ready printer and press any key !" you can press 'F' to direct the output to a file. The names of the files created are as follows.

Data --->

Results --->

Defaults --->

4.3 Analyze Option

The following menu is displayed when you select this option in the main menu from which you can select the mode of processing.

Trail - The trial option is for you to see the results by changing different parameters. The results are not recorded in the history file in trial runs.

Final- In final option the results are recorded with a given trial number which is requested to input from the user. If you select Y for the question 'Delete previous records for the same conditions? (Y/N) ' the history records for the same trial number which you have recorded from a previous run are deleted.

Quit - To return to main menu

4.4 Process option

The process option displays the following menu where you can carry out a optimisation/sensitivity type analysis and option to print the results of the analysis done.

Optimize - To carry out sensitivity/optimisation analysis

Print - To get the print out of the results of analysis

Quit - To return to previous menu

4.4.1 Optimize option

This option is used to carry out a optimization/sensitivity analysis to arrive at the maximum probable command area of a tank for a given set of conditions. An iterative approach is is used with a user difinable iteration step (steps of command area) and a maximum allowable limit of command area. The system provides the facility to vary following.

1. R/F pattern - select the rainfall pattern file saved in the default drive
2. Method of yield calculation - (out of 6 methods described elsewhere - PgDn key activates a menu at this option)
3. Iteration Step - (1,2,5,10 etc. acres)
4. Maximum command area (eg. 1000 acres where iteration stops at this upper limit)
5. Cropping pattern - Possible to change the cropping pattren

6. Start dates list - the start dates list could be changed if necessay

The process option is very important and useful as it carries out both optimisation and sensitity type analysis. All the other data items related to system, cliematic and parametric data could be changed through data option in the main menu. The results of each analysis is saved in a database file with the extension .OCA (optimum command area) and having the same file name as system.

4.4.2 Print option

By pressing the key F at the prompt 'ready printer and press any key...!", you can direct the output to a print file. The name of the print file is formed by adding .PRN to the default system id.

4.5 Output Option

Upon selection of this main menu option a pop-up box menu consisting of the following options.

Data - To get print out of the input data for checking purposes

Results - To get print outs of the results obtained for the reservoir with conditions and parameters as given

Other - The current settings of default parameters. (see defaults menu option for a list of default parameters)

4.6 History Option

The history option in the main menu displays a pop-up box menu consisting of following options.

Maintain - The records in the history file are displayed on screen so that you can make any changes to records and go up and down and browse.

Analyze - Nothing has been assigned for this option in this option.

Erase - This option is to erase the records for a given trial number.

Print - This is to get a print out of the records in the history file.

4.7 Default Option

The default option in the main menu displays a pop-up box menu consisting of the following options.

Defaults - To change current set of default parameters.

Back up - To keep a backup copy of the current system including data in a diskette.

Restore - To get back a backed up system.

SetColor - To set default colors of various screens of the program, interactively.

ResetColor - To set the default colors to author selected set of colors.

Quit - To return to main menu.

4.7.1 List of default parameters

Description		Preset Default
1. Default system Id		SAMPLE
2. Description		Sample tank system
3. Automatic backup feature ON?	Yes	
4. Start up checks ON		Yes
5. Animated processing?	Yes	
6. Rainfall probability	75%	
7. Yield calculation method		1 (ID standard method)
8. Menu wrapping feature	ON	
9. Save data before final processing?	Yes	
10. Treat losses before releases?	No	
11. Back up drive (ABCD)	A	
12. Graphical representation on screen?	Yes	
13. Save changes to default parameters?	Yes	
14. Consider direct rainfall contribution?	Yes	
15. Consider drainage contribution?	Yes	
16. Consider effective rainfall on farm?	Yes	

A selected set of important default parameters are described below. The other parameters are self explanatory from it's prompt and most of them are on/off switches.

4.7.2 Method of calculation of yield

You can type a digit to select the method of calculating of yield. Refer chapter 3.1 for a list of allowable choices.

4.7.3 Animated Processing? Y/N

You can set this to Y to stop after calculation of the balances for each month allowing you to see the results on the screen for the current month for validating purpose. If you set this to N then calculation process continues for all six month in the Maha season without pausing after each month. Finally the graph of variation of the storage in the reservoir is displayed on screen allowing you to decide on whether you want to review the input data in the next trial run.

4.7.4 Display the graphical representation on screen always? Y/N

You can switch off and on the structure drawing on the screen representing different inputs, outputs of a reservoir. This will be useful to get some idea of the purpose of the program. The numerical figures obtained for the given parameter is displayed in the space reserved when the processing is done through Analyze option.

4.7.5 Backup drive : (ABCD)

You can set the drive used as default for backup and restore operations.

4.7.6 Direct rainfall contribution (Considered/Not)

The direct rainfall contribution on tank surface can be considered or ignored for the analysis by setting this option to Yes or No.

4.7.7 Drainage contribution (Considered/Not)

The drainage contribution from the up-stream paddy and other farms could be considered or not for the analysis by setting this option to Yes or No.

4.7.8 Effective rainfall on farm (Considered/Not)

The effective rainfall on farm which supplies a part of the crop water requirement for cultivations could be considered or not by setting this option to Yes or No.

APPENDIX A - NOTE OF THANKS

Special thanks are due to the staff of International Irrigation Management Institute, Sri Lanka Field Operations Division for employing the author for the development of this version of the software package. The contract was completed in a time frame of 10 days and during this short period the kind assistance extended to the author is gratefully acknowledged. The author wishes to note the names of Dr. Shaktivadivel and Mr. Nihal Fernando as key personnel at the IIMI who guided and supervised the software development process.

Sivalkulama Tank F10

Reservoir Parameters

Reservoir ID	SIVAL
Description	Sivalkulama Tank F/10
Spill Level (Ft)	107.50
Spill Volume (Ac.ft)	492.64
Dead Level (Ft)	100.00
Dead Storage (Ac.ft)	0.00
Initial Volume (Ac.ft)	0.00
Initial Level (ft)	100.00

Area-Capacity Curve Type :D- Table

Reservoir Characteristic Curve

Height	Area	Capacity
100.00	9.49	0.00
101.00	22.40	15.95
102.00	36.06	45.18
103.00	56.45	91.44
104.00	70.20	154.77
105.00	86.14	232.94
106.00	98.00	325.01
107.00	116.40	432.21
107.50	125.31	492.64
107.50	125.31	492.64

Specific yield for MAHA season : 350.00

Probability Rainfall Table

Month	90%	80%	75%	70%	65%	60%	50%
OCT	12.0	44.0	5.0	22.0	44.0	22.0	11.0
NOV	33.0	44.0	6.0	0.0	5.0	22.0	34.0
DEC	55.0	66.0	5.0	22.0	12.0	5.0	66.0
JAN	222.0	44.0	3.0	22.0	55.0	66.0	22.0
FEB	44.0	33.0	1.0	55.0	11.0	333.0	33.0
MAR	44.0	55.0	2.0	77.0	88.0	22.0	33.0
APR	22.0	44.0	5.0	66.0	44.0	33.0	22.0
MAY	55.0	333.0	2.0	33.0	55.0	33.0	32.0
JUN	45.0	34.0	0.5	45.0	34.0	76.0	87.0
JUL	23.0	65.0	0.0	45.0	35.0	45.0	87.0
AUG	23.0	45.0	0.5	34.0	44.0	22.0	33.0
SEP	22.0	12.0	1.0	44.0	4.0	2.0	33.0

No. of crops : 2

Crop pattern Table (Planned)

	------US---------		---------DS-----------	
Crop	Area	Start	Area	Start
PADDY	588.80	01/10/94	109.00	01/10/94
CHILLE	0.00	01/10/94	0.00	01/10/94

Catchment Area Table

No. of components : 1

Catchment Area	Coefficient
588.80	1.0

Crop water requirement(Base Crop)

Total Number of crops : 5

	Initial		Develop		Mid		late	
Crop	Days	Kc	Days	Kc	Days	Kc	Days	Kc
CHILLE	25	0.65	25	0.85	75	1.00	25	0.90
PADDY	30	1.00	40	1.15	45	1.20	20	0.90
	0	0.00	0	0.00	0	0.00	0	0.00
	0	0.00	0	0.00	0	0.00	0	0.00
	0	0.00	0	0.00	0	0.00	0	0.00

Evapo-transpiration Table

Month	ET0 cefficient
OCT	6.20
NOV	4.30
DEC	4.50
JAN	4.70
FEB	5.00
MAR	6.20
APR	5.90
MAY	6.40
JUN	6.90
JUL	7.50
AUG	7.60
SEP	7.50

Evaporation Coefficient Table

Month	Evaporation cefficient
OCT	0.35
NOV	0.29
DEC	0.31
JAN	0.32
FEB	0.36
MAR	0.49
APR	0.41
MAY	0.42
JUN	0.44
JUL	0.45
AUG	0.49
SEP	0.48

Seepage Coefficient : 0.05

Application efficiency : 60.00

Application efficiency : 70.00

Data for Regression modelling

Number of years : 5

Year	Rainfall	Evaporat	Runoff
1	1.0	3.0	6.0
2	2.0	4.0	8.0
3	3.0	4.0	8.0
4	4.0	5.0	10.0
5	5.0	6.0	12.0

Sivalkulama Tank F10

Default Parameters - Trial No : 0

System Identity : SIVAKULA

System Description : Sivalkulama Tank F10

Automatic Backup feature : ON

Integrity checks feature : ON

Menu wrapping feature : ON

Saving data before processing feature : ON

Treat losses before processing feature : ON

Backup drive : A

Display structure drawing : Yes

Selected Rainfall Probability : 75%

12/10/94/ROSES2.00/IIMI/ESC

Sivalkulama Tank F10

Optimization Analysis Report
Irrigable Maximum Command Area (Acres)

R/F Pattern	Yield Calculation	Crop Pattern	Start Date of Cultivation 01/10/94	15/10/94	01/11/94	15/11/94	01/12/94	15/12/94
DL1	1	100% Paddy	50.00	80.00	70.00	80.00	70.00	70.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	54.00	81.00	72.00	81.00	63.00	72.00
		10% Chille	6.00	9.00	8.00	9.00	7.00	8.00
	2	100% Paddy	0.00	10.00	30.00	40.00	40.00	40.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	0.00	9.00	27.00	36.00	36.00	45.00
		10% Chille	0.00	1.00	3.00	4.00	4.00	5.00
	4	100% Paddy	50.00	80.00	70.00	70.00	60.00	70.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	54.00	72.00	63.00	72.00	63.00	63.00
		10% Chille	6.00	8.00	7.00	8.00	7.00	7.00
	5	100% Paddy	40.00	70.00	60.00	70.00	60.00	60.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	45.00	63.00	63.00	63.00	54.00	63.00
		10% Chille	5.00	7.00	7.00	7.00	6.00	7.00
	6	100% Paddy	10.00	20.00	40.00	40.00	40.00	40.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	9.00	18.00	36.00	45.00	36.00	36.00
		10% Chille	1.00	2.00	4.00	5.00	4.00	4.00
HORO	1	100% Paddy	60.00	80.00	90.00	90.00	80.00	90.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	54.00	81.00	81.00	90.00	81.00	81.00
		10% Chille	6.00	9.00	9.00	10.00	9.00	9.00
	2	100% Paddy	0.00	10.00	50.00	50.00	50.00	60.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	0.00	9.00	54.00	54.00	45.00	54.00
		10% Chille	0.00	1.00	6.00	6.00	5.00	6.00
	4	100% Paddy	60.00	80.00	80.00	90.00	70.00	80.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	54.00	81.00	81.00	81.00	72.00	72.00
		10% Chille	6.00	9.00	9.00	9.00	8.00	8.00
	5	100% Paddy	50.00	70.00	80.00	80.00	70.00	70.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	45.00	72.00	72.00	81.00	63.00	72.00
		10% Chille	5.00	8.00	8.00	9.00	7.00	8.00
	6	100% Paddy	10.00	20.00	50.00	50.00	40.00	50.00
		0% Chille	0.00	0.00	0.00	0.00	0.00	0.00
		90% Paddy	9.00	18.00	45.00	54.00	45.00	45.00
		10% Chille	1.00	2.00	5.00	6.00	5.00	5.00

ANNEXURE 6

AN ANALYSIS OF GROUNDWATER RESOURCES, ITS ESTIMATION AND ABSTRACTION THROUGH AGROWELLS IN ANURADHAPURA DISTRICT

1. HYDROGEOLOGY OF ANURADHAPURA DISTRICT

Anuradhapura district being a part of the crystalline basement complex of Sri Lanka, possesses hydrogeological conditions similar to the hard rocks of many other tropical regions.

Occurrence of groundwater in the district is mainly in association with weathered overburden of the basement rocks. Almost everywhere in the district, the bed rock is covered with an overburden of in-situ weathered material of the parent rocks. The thickness and the composition of the overburden depends on the mineralogical composition of the parent rock, geomorphology of the location, and relative easiness for weathering of the parent rock. The majority of dugwells in the district are constructed within the overburden.

The district consists of entirely crystalline rocks such as charnockite, granite gneiss, quartzite, and hornblende biotite gneiss. Basically there is no primary porosity in any of these rocks but a secondary porosity has been developed in all the rocks; however to varying degrees depending on the intensity of jointing and/or fracturing of the rocks as a result of tectonic influence. Quartzite is the most intensively fractured and/or jointed rock and shows more than 100 joints of 2-3 different systems per m^2 of surface rock. Charnockite and charnockite gneisses show only a limited number of joints (3-4 at maximum per m^2 of surface rock). All other rock types show joint intensity between those of quartzite and charnockite (COWI Consult. 1993).

Table 13 gives the dominant hydrogeological characteristics and water yielding capabilities of the predominant rock types found in Anuradhapura district.

Table 13. Characteristics of rock type and their water yielding capabilities.

Sr. No.	Type of rock	Area covered	Hydrogeological conditions and well yields
1	Charnockites and Charnockitic Gneiss	50% of the total area	Less promising hydrogeological conditions; low yield
2	Garnet Biotite	15-20% of the area	Weathering upto 10 m. Promising aquifer for construction of dugwells
3	Granitic Gneiss	Less in areal extent	Form low elevated ridges; overburden 3-4 of mainly clay; poor aquifer
4	Quartzite	Less than 10% of the area	Low ridges with gentle slopes; fracturing and jointing very common; thick overburden layer of about 20 m; good aquifer
5	Hornblende Biotite Gneiss	5-10% of the area	Rock covered with overburden; poor yield

2. GROUNDWATER TABLE BEHAVIOR IN THE DRY ZONE

A contour map showing yearly fluctuations in groundwater level of Anuradhapura district is shown in **Figure 11.**

The studies carried out at Maha Illupalama Research Station and reported by C.R. Panabokke (Panabokke, 1958) on groundwater table behavior (illustrated **in Figure 12)** is typical of many other watershed areas in the dry zone. This depicts the groundwater table fluctuations of an aquifer zone away from the influence of tank storages. The highest and lowest positions of the wet season water table, which have been recorded since 1951 are shown in **Figure 12.** Based on the detailed observations, he made the following conclusions: (a) on the ridge and the upper slopes there is no water table evident within the depths to which the borings were made. While this is so during a normal rainfall season, in a season of unusually excessive rainfall, the water table rises to within 0.90 m of the surface. This land class is therefore well-drained during the wet season, (b) in the middle and upper slopes the groundwater rises to the surface for a short period, but it disappears during the dry season. This land class is therefore relatively poorly-drained during the wet season, and (c) the bottom lands are poorly-drained during the greater part of the year because the water table rises to the surface for long periods, and falls to within 0.90 m to 2.5 m of the surface during the dry season.

During the wet season, in spite of the good internal drainage of the profile, the impervious nature of the underlying rock prevents vertical drainage and the groundwater level after the onset of the rains raises very rapidly. In Huruluwewa catchment, it was observed that after a rainfall of about 150 mm in the month of September, most of the water table in wells reached very near to the ground surface and during the dry season it drops at an average rate of about 0.60 m per month.

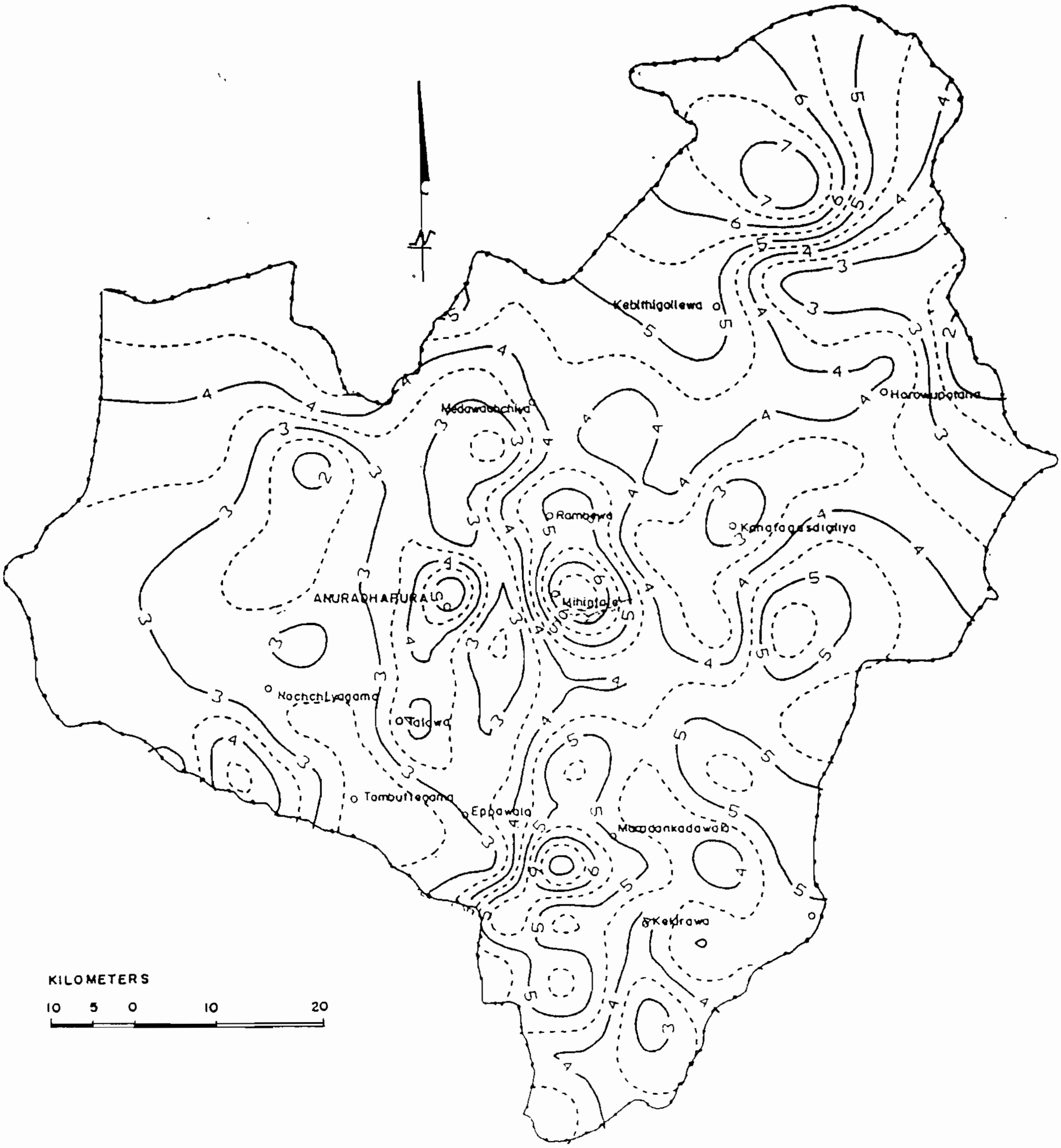

Figure 11 - Contour map showing yearly fluctuations in groundwater level.

Soil Science. (Vol 87.) 1959 Feb.

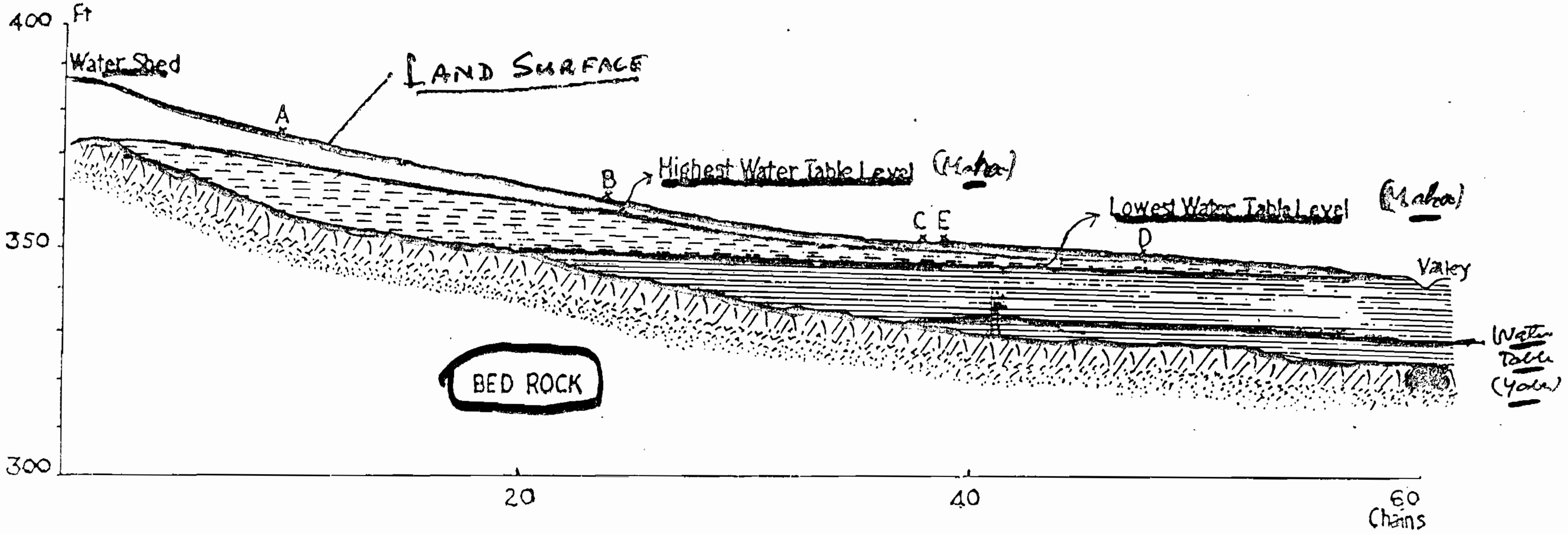

Figure 12 Ground-water table behavior

3. TYPE OF GROUNDWATER AQUIFERS

The Anuradhapura Drinking Water Supply Master Plan (AMP) Study Team conducted about 35 tubewell pumping tests in Anuradhapura district (COWI Consult, 1993). Their analysis of drawdown and recovery data indicates the following two types of aquifers.

1) Unconfined to semi-confined aquifers with relatively high transmissivity, but limited areal extent which after a few hours of pumping shows characteristic boundary effects. Another type is unconfined aquifers which rapidly reach a state of semi-equilibrium drawing water from a high yield aquifer which over the pumping period results in overall low drawdowns.

2) The second type of aquifers contrary to the first group appear to be located in areas where there is a good hydraulic contact between water saturated fractures and a high yield aquifer in the overburden (leaky aquifers).

The simultaneous water level measurements carried out by this team on dug- and tubewells confirm the hypothesis that there exists one to one correspondence between the water levels observed in the dug- and tubewells due to the prevalent hydrogeological conditions in the Anuradhapura district. In other words, the deep aquifers can be classified as leaky aquifers. **Table 14** presents a list of statistics from agrowell survey conducted by this team based on 179 wells in the upland areas.

Table 14: Statistics from Agrowell survey based on 179 wells (upland area).

Parameters	Depth/ m	Diameter m	MWL m	HWL m	LWL m	Yala acre	Maha acre
Mean	6.4	5.4	3.5	1.9	5.0	1.1	2.0
Std. devi.	1.6	1.2	1.2	1.3	1.6	0.9	1.5
min.	2.1	1.8	0.3	0.1	0.4	0.1	0.3
max.	8.8	11.0	7.0	6.7	9.1	5.0	8.0

SOURCE: COWI Consultants.

MWL = measured water level;
LWL = Lower water level;
HWL = Highest water level
Depth from the ground surface (MSL)

4. WATER LEVEL FLUCTUATIONS IN AGROWELLS OF LOW LYING PADDY AREAS

Agrowell statistics are not readily available for irrigated low land areas
However, as part of this study, the consultants who were hired to map the land use gathered information on area irrigated, total cultivable area, number of wells, their depth and diameter, highest and lowest water levels and other details. The water level fluctuation for each well was then determined by calculating the difference between the highest and the lowest water levels. The statistics of lowland agrowells is presented in **Table 15**. The calculated average fluctuation over a period of one year works out to 4.60 m.

It must be noted that the water level fluctuation indicated in the Table is the maximum. However, within a season or a year it will be different in a particular well.

Table 15: Particulars from Agrowell Survey Based on 54 Wells (Both Upland and Lowland Areas)

Parameter	Depth of well m	Diameter m	LWL m	HWL m	Water level fluctuation m
Mean	6.1	5.8	7.6	2.7	4.6

SOURCE: Survey Team data under this contract.

5. RECHARGE ASSESSMENT

Estimates of the recharge are frequently made based on rise in the water table during the rainy season. The principle in calculating recharge by this method is that recharge causes a rise in groundwater level, which is directly proportional to the recharge and inversely proportional to the specific yield of the water table aquifer. Thus, the recharge is calculated by multiplying the observed rise in water level by the specific yield of the aquifer.

This method involves a fair amount of inaccuracy. The values may be higher than the fluctuations in an average year, because the reported highest water level presumably coincides with a very wet year and the reported lowest water level coincides with a very long dry period. The fluctuations are also influenced by the amount of water withdrawn from the wells. However, the information obtained seems to be consistent, and is believed to give a reliable impression of the order of magnitude involved. This method is used in this analysis.

6. SPECIFIC YIELD

The specific yield, in practice, may be considered to equal the effective porosity or drainable pore space of the aquifer. Estimates for specific yields are available for different aquifer materials in literature.

The following values of specific yield as used in India is given in **Table 16** below.

Table 16: Values of Specific Yield

Material	Range of specific yield (%)
Sandy alluvium	12-18
Valley fills	10-14
Silt/clay rick alluvium	5-12
Sandstone	1-8
Limestone	3
Highly Karstified limestone	7
Granite	2-4
Basalt	1-3
Laterite	2-4
Weathered phyllites, shales, schists and associated rocks	1-3

For the prevalent rock types in Anuradhapura district, specific yields in the range from 2-4 percent are considered appropriate. (COWI, Consultants, 1993).

7. REFERENCE CROP EVAPOTRANSPIRATION (ET)

Reference crop evapotranspiration for Anuradhapura based on data from Maha Illupalama shown in **Table 17.**

Table 17: Evapotranspiration Values

Month	ET in mm
January	119
February	127
March	157
April	149
May	162
June	175
July	190
August	193
September	190
October	157
November	109
December	114
Total	1842

8. CROPS AND CROPPING CALENDAR

The most commonly grown crops under agrowells in the upland area are chili, big-onion, vegetables, etc. In the case of chilli, farmers start their cultivation with the maha rain and make use of the maha rain in the months of October, November and December. They need irrigation water only during January, February and March. On the other hand, some of the farmers wait till December and start a 'meda' crop in January and go upto middle of April. Then from mid-April upto July/August second OFC is taken in these uplands.

While this is the practice in the upland area, in the lowland paddy area, very few farmers use well water during the maha season to raise any OFCs. It is only during the yala season, (starting from mid-April upto July/August) farmers go for an OFC crop, especially in the 'Akkarawela' area.

9. AREA IRRIGATED PER AGROWELL IN MAHA AND YALA SEASONS

The COWI Consultants in their survey of 167 agrowells indicated (**Table 2**) that the average extent irrigated in the upland area during the maha and yala seasons is 2 acres ad 1.1 acres respectively. Our survey during this study indicated that farmers in the lowlying akkarawela paddy area irrigate about 1 acre with OFCs during the yala season.

10. CROP WATER REQUIREMENT FROM AGROWELLS FOR MOST COMMON CROPS (Figures in mm)

Based on the crop, crop calendar, ET, area irrigated during maha and yala both upland and lowlands, the following table is prepared. **(See Table 18 below.**

Table 18: Water Requirements from a Typical Dug-well in Yala and Maha Seasons

Details	Maha	Yala
Crop water requirement, A = ET x Kc*	322	636
B = Application efficiency	80%	80%
C = conveyance efficiency	80%	80%
Water requirement at D = A/B/C from source	503	795
F = Effective rainfall	***	150**
Water requirement from source adjusted for effective rainfall W = D - F	503	645
Water requirement from a dugwell	4020M³	2830M³

NOTE: An upland agrowell in a year would draw about 7000m³ of water while a lowland well would draw about 3000 m³ of water.

* = An average value of 0.8 assumed for this computation.

** = An effective rainfall of 150 mm based on April/May rain has been assumed.

*** = Farmers start their cultivation of OFC in the settled chena (with dugwells) with the on-set of monsoon in the months of October, November and December. During this period, they rarely use well water. The well water is used only during January, February and March. Also some farmers wait till December and start their maha cultivation starting December. In either case effective rainfall used during irrigation period is zero.

11. WATER QUALITY IN ANURADHAPURA DISTRICT

11.1 Surface Water Quality

COWI Consult (1993) has carried out a detailed sampling and analysis of surface water quality of existing water bodies in Anuradhapura district. The sampling has been carried out over a period of two seasons and at 18 sampling points. Their interpretation of surface water quality is summarized in **Table 19** below.

Table 19: Surface Water Quality Indicators - Anuradhapura District

Sr. No.	Parameter	Range	Remarks
1	Turbidity	7 - 50	No seasonal trend 7 - Polgolla 50 - Rajangane
2	PH	6.4 to 8.0	6.4 - Polgolla 8.0 - Rajangama No seasonal trend
3	EC	60 to 1500	No seasonal trend 60 - Polgolla 1500 - Rajangane
4	Total hardness	20 to 1500	No seasonal trend 20 - Polgolla 1.8 - Kala wewa
5	Ammonium	0.1 ppm to 1.8 ppm	Value below 1, natural conditions 0.1 - Polgolla 1.8 - Nachchaduwa Higher value indicates contamination from human source or from manure.
6	Nitrates	0.4 - 9 ppm Typical values around 1.5 ppm	No significant seasonal trend. Signifies impacts of fertilizer, manure or human excreta.
7	Phosphates	0.15 ppm to 1.2 ppm	0.15 ppm at Polgolla 1.2 ppm at Huruluwewa Typically derived from fertilizer, manure human excreta.
8	Fluoride	< 1 ppm	Impact is felt only when it is 2 to 3 ppm

One of the findings of this investigation is almost all parameters described above follow a trend towards increasing values downstream. This is particularly important to note since these parameters give an indication of increased contamination from agro-activities, manure and human wastes. The data indicates that irrigated agriculture in the district has a significant impact on water quality.

11.2 Groundwater Quality

The following information is extracted from COWI Consult (1993).

Nitrate: The nitrate concentrations found in Anuradhapura district so far, do not involve any health risks. (About 60% of the dugwells tested contained nitrate concentration greater than 5 mg/l). The presence of nitrate in the groundwater, however, shows that the groundwater aquifers in the district do not possess an effective reduction capacity which could reduce infiltrating nitrate to gaseous nitrogen. This means that continuous infiltration of water polluted with nutrients from fertilizers, manure and human wastes gradually will dilapidate the groundwater quality. The fact that nitrate concentration do not follow a set pattern (as other parameters such as magnesium, sulphate, chloride total hardness, fluoride, etc.) indicates that nitrate concentrations are more associated with the other factors such as land use and different human activities.

Ammonia: The Sri Lankan standard gives a maximum permissible level for ammonium of 0.15 mg/l. Ammonium concentration in groundwater indicates pollution from livestock manure, waste water, etc. Samples tested from dug- and tubewells indicate that a greater percentage of samples have higher ammonium content in dugwells than in tubewells. This indicates that the ammonium content may be associated with surface near pollution and thereby be an indication of environmental impacts from land use activities.

Phosphate: Like for ammonia the maximum permissible level for phosphate established at 2.0 mg/l is not based on health considerations but selected with the purpose of registering possible pollution from the surroundings. The naturally occurring phosphate concentrations rarely exceed 0.5 mg/l. Only one water sample tested from tubewells (out of 244) exceeded the 2.0 mg/l level while 14% of the samples from dugwells (out of 58) exceeded the maximum permissible level.

The general level of phosphate concentrations with the majority of values above 0.5 mg/l suggests, however, that agricultural and other human activities have an environmental impact on the groundwater quality. This also explains the fact the surface near water abstracted from dugwells display higher phosphate values than samples from tubewells.

It can be concluded that there is a widespread occurrence in groundwater of nutrients as nitrate, ammonia, and phosphate in the Anuradhapura district. The fact that the locations of wells with high concentrations of these parameters do not follow a general pattern

supports the assumption that the anomalous values are not caused by hydrogeological factors.

The presence of these pollution indicators were more prevalent in dugwells than in tubewells. This would be expected as dugwells are fed by the upper portion of the groundwater aquifer.

These findings confirm that there is an environmental impact on the groundwater resources from different land use activities. Although the concentrations are not high enough to constitute a health risk, it is necessary to address the problem through careful monitoring of these parameters as soon as possible to avoid unsurmountable problems at a latter stage.

12. GROUNDWATER ESTIMATION UNDER EACH TANK IN A TANK CASCADE

The following are the steps involved in groundwater estimation in a cascade system:

Step (1): Prepare a detailed land use map of the micro-watershed (cascade system) indicating the catchment area contributing to the tank, tank waterspread, lowlands paddy area, upland chena, scrub and homestead (settlement, recent chena, old chena) area, and upland area contributing to drainage through paddy land. It is essential to use 1:10,000 maps with 5 ft contours to delineate these areas more carefully and then field check the map prepared.

Step (2): Find out the area of each of the above category of land including tank storage.[7]

Step (3): Identify the hydrogeological condition of the micro-catchment such as weathered overburden, number of agrowells, number of drinking water supply wells, groundwater level fluctuation, etc. This can be obtained from participatory resource mapping techniques.

Step (4): Estimate the recharge rate from catchment area, tank water spread area and paddy irrigated area[8].

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[7] Use the thumb rule V = 0.4 X A X D where V is the tank storage, A is the waterspread area assessed from topographical sheets of the Survey Department or 1:10,000 maps and D is the average full supply depth at sluice head.

[8] The average recharge in the catchment area of the dry zone has been worked out by a number of investigators as 110 mm/year. Of this, 50 percent would be allowed for maintaining flora and fauna of the catchment and for base flow, and the remaining 50 percent is available for extraction through wells.

Step (5): Estimate the recharge contributed by the catchment area, tank waterspread area and paddy irrigated area. The sum of all these three components gives the total estimates of groundwater available for extraction.

Step (6): Find out the present groundwater used by:

a) Tube- and dugwells for drinking water supply,
b) Agrowells.

Estimate the groundwater extraction from an agrowell in the upland area which uses groundwater both during maha and yala seasons and an agrowell situated in the lowlying paddy area which abstracts groundwater only during the yala season.[9]

The drinking water supply as per COWI Consultant works out to 1 mm/ha of micro-watershed. The present use of groundwater can be evaluated by knowing the number of agrowells in the upland area and multiplying by 7000 and the number of agrowells in the lowlying paddy land multiplied by 3000.

Step (7): The difference between quantity of groundwater estimated under **Step (5)** and **Step (6)** gives the groundwater available for further extraction.

Step (8): Determine the number of additional agrowells that can be constructed within the micro-watershed taking into consideration the irrigable area available both in the upland and in the lowlying paddy land.

The average recharge under the tank waterspread is equal to 160 mm which is governed by the weathered formation and not the water availability.

For paddy irrigated land, the recharge rate is equal to groundwater level fluctuations multiplied by the specific yield, (i.e if 7.5 m is the groundwater level fluctuation then the recharge in irrigated paddy area = 7.5 x 20 = 150 mm, where 20 mm is specific yield/meter.

[9] A method is indicated under Section 10 of this annexure to compute groundwater extraction from an agrowell based on the crop and the areal extent irrigated. By this method, it is estimated that an agrowell in the upland area would use 7000 m^3 of water per well while that in the lowlying paddy land would use only 3000 m^3 of water per agro-well. This is because upland agro-well uses water both during maha and yala seasons while agro-well in the lowlying paddy land uses well water only during the yala season.

A NUMERICAL EXAMPLE FOR COMPUTING A NUMBER OF AGROWELLS UNDER A TANK

The following are the assumptions and hypothetical data used in the illustrative example.

Assumptions

(1) The number of agrowells computed under a tank includes both agrowells in the lowland paddy area and agrowells in the highland area (chena, homestead and catchment).

(2) The upland agrowells will irrigate on an average 2 acres in maha and 1.1 acres during yala while agrowells in the lowland paddy area will irrigated on an average 1.0 acre of OFC during yala and no well cultivation during maha.

(3) Agrowells in the upland area will start groundwater use from January upto mid-'April for a maha crop and thereafter upto August for a yala crop. Agrowells in lowland paddy area will use groundwater from mid-April to August for OFC crop.

(4) The groundwater recharge is contributed by the following sources: i) rainfall, ii) tank water, and iii) irrigation seepage and percolation water.

(5) The area contributing to recharge is: i) catchment area including those draining into the lowland paddy area, ii) tank waterspread area, and iii) lowland paddy area.

(6) The recharge in the catchment area is restricted by rainfall amount while the recharge in tank waterspread and the low-lying paddy area is restricted by underground weathered formation.

(7) Groundwater extraction per dug well is estimated based on the area irrigated, crops grown, and their water requirement. Because of the differing cropping calendar, agrowells in lowland areas and upland areas will abstract different quantities of water.

(8) Fifty percent of the recharge will be assumed to be necessary for maintaining base flow and the flora and fauna of the area. (i.e., only 50 percent of the recharge is available for groundwater extraction).

Data Used

(1)	Catchment area (ha):	=	860
(2)	Tank water spread area (ha):	=	100
(3)	Lowland paddy area (ha	=	40
(4)	Recharge in the catchment area (mm):	=	110
(5)	Recharge in the tank waterspread areas (mm):	=	160
(6)	Recharge in the paddy area (mm):	=	150
(7)	Recharge available for groundwater extraction:		
	(i) in catchment	=	55 mm
	(ii) in waterspread	=	80 mm
	(iii) in paddy area	=	75 mm
(8)	Number of upland agrowells:	=	10
(9)	Number of paddy area agrowells:	=	2
(10)	Yearly abstraction by an upland agrowell in the upland area:	=	7000 m^3/well
(11)	Yearly abstraction by lowland agrowell:	=	3000 m^3/well

Groundwater Estimation

(1) Estimated groundwater availability:

$$= 860 \times 10^4 \times \frac{55}{1000} + 100 \times 10^4 \times \frac{80}{1000} + 40 \times 10^4 \times \frac{75}{1000}$$

$$= 10^3 (473 + 80 + 30) = 583 \times 10^3 \text{ m}^3$$

(2) Estimated present groundwater use:

$$= 10 \times 7000 + 2 \times 3000 = 76 \times 10^3 \text{ m}^3$$

(3) Balance groundwater available for extraction:
= $507 \times 10^3\ m^3$

(4) Groundwater available in the upland area:
= $403 \times 10^3\ m^3$

(5) Groundwater available in the tank and paddy area:
= $104 \times 10^3\ m^3$

(6) Number of additional agrowells in the upland area:
$$= \frac{403 \times 10^3}{7 \times 10^3} = 58$$

(7) Number of additional agrowells in the lowland area:
$$= \frac{104 \times 10^3}{3 \times 10^3} = 35$$

(8) Total number of wells in the upland area:
= 68

(9) Extent of upland area required to support 1 agrowell:
$$= \frac{860}{68} = 12.5 \text{ ha}$$

(10) Total number of wells in the lowland area:
= 37

(11) Extent of lowland area required to support 1 agrowell:
$$= \frac{40}{37} = 1 \text{ ha}$$

Concluding Remarks

For the chosen set of parameters, approximately 12.5 ha is required to support one agro-well in the highland area (chenas, homestead, catchment), while 1 ha is required to support one agrowell in the lowland paddy areas. However, this may vary depending on the areal extent of tank and command area, catchment area and renewable annual recharge rate. For representative values of these parameters as obtained in the field, the surface areas required to support agrowells both in the highland and the lowland need to be worked out. Field measurements indicate that there exists good hydraulic continuity between tank water spread and command area. Observation of water levels carried out in Kurunegala District (North-Western Province, Sri Lanka) and Padianallur in Madras (India) indicate a very good correlation between tank water level and groundwater levels in the command area. Therefore, the assumption that agrowells in command would be able to draw upon the groundwater under tank waterspread area appears to a valid assumption. Also, these are the areas for further studies during implementation of this area development project.

ANNEXURE 8

TECHNICAL, WATER RESOURCES, MANAGEMENT AND SOCIO-ECONOMIC ANALYSIS

(A) TECHNICAL ANALYSIS

The technical analysis will be carried out by a qualified person, preferably by a Technical Officer of the Irrigation Department or the Agrarian Services Department. The following questionnaire will be used: (Note Y = Yes; N = No)

1. Tank Catchment (Y = 1, N = 0)

(a) Land Use of the catchment (in percentage):

- (i) Forest .....
- (ii) Recent chena .....
- (iii) Homestead .....
- (iv) Scrub .....
- (v) Rock-knob plains (RKP) .....

(b) Soil conservation measures adopted in the catchment: (Y/N)

(c) Is the catchment intercepted by roads and settlement schemes: (Y/N)

(d) Is runoff to tank blocked by clogged culverts, silted drainage ways and obstructions: (Y/N)

2. Tank Bed (Y = 1), N = 0)

(a) Is tank bed silted up: (Y/N)

(b) If silted up, what is the percentage: ....Percent

(c) Is tank bed siltation a reason for water shortage: (Y/N)

(d) Is tank bed cultivated by encroachers: (Y/N)

(e) Is tank bed infested with aquatic vegetation: (Y/N)

(f) If yes, extent of vegetational cover: ....Percent

3. <u>Tank Bund</u> (Y = 1), N = 0)

(a) Is tank bund leaking: (Y/N)

(b) If tank bed is leaking, in what reaches is it leaking: .....

(c) Does the bund need raising: (Y/N)

(d) Does the side slopes need re-establishing: (Y/N)

(e) Is tank bund used as a road to enter the village: (Y/N)

(f) If tank bund is used as a road, does it need widening and gavelling: (Y/N)

4. <u>Sluices</u> (Y = 1, N = 0)

	LB	MID	RB
(a) Location of the sluices:	.....	.....	.....
(b) Type and size of the sluices:	.....	.....	.....

(c) Present status of the sluices:

	LB	MID	RB
(i) Old sluice need full replacement:	(Y/N)	(Y/N)	(Y/N)
(ii) Sluice sill levels are faulty:	(Y/N)	(Y/N)	(Y/N)
(iii) Sluice gates not functioning:	(Y/N)	(Y/N)	(Y/N)
(iv) Only the sluice gate rods need repairs or replacement:	(Y/N)	(Y/N)	(Y/N)

(v) Only sluice gate locking arrangement required:	(Y/N) (Y/N) (Y/N)
(vi) Channel approach to the sluice within the tank bed needs improvement:	(Y/N) (Y/N) (Y/N)

5. Spill (Y = 1, N = 0)

	LB	MID	RB
(a) Location of spills:	(Y/N)	(Y/N)	(Y/N)
(b) Type and length of gate sizes and number:	(Y/N)	(Y/N)	(Y/N)
(c) Present status of the spill:			
(i)) Spill needs full replacement.	(Y/N)	(Y/N)	(Y/N)
(ii) Spill crest level has to be raised.	(Y/N)	(Y/N)	(Y/N)
(iii) Only spill leakage has to be arrested.	(Y/N)	(Y/N)	(Y/N)
(iv) Downstream protection has to be provided.	(Y/N)	(Y/N)	(Y/N)
(v) Spill approach channel has to be desilted.	(Y/N)	(Y/N)	(Y/N)
(vi) Spill tail channel has to be cleaned.	(Y/N)	(Y/N)	(Y/N)

6. Irrigation Distribution System (Y = 1, N = 0)

	LB	MID	RB
(a) Location of main channels:	.....	.....	.....
(b) Command area under the channels (ha):	.....	.....	.....
(c) Total length of the channels (m):	.....	.....	.....

(d) Present Status:

		LB	MID	RB
(i)	Channel system non-existent.	(Y/N)	(Y/N)	(Y/N)
(ii)	Channel system exists, but heavily dilapidated.	(Y/N)	(Y/N)	(Y/N)
(iii)	Channel system exists but moderately dilapidated.	(Y/N)	(Y/N)	(Y/N)
(iv)	Channel system is in good condition.	(Y/N)	(Y/N)	(Y/N)
(v)	Channel bunds to be redone:	(Y/N)	(Y/N)	(Y/N)
(vi)	Channel irrigation structures to be provided.	(Y/N)	(Y/N)	(Y/N)
(vii)	Channel layout to be redone.	(Y/N)	(Y/N)	(Y/N)
(viii)	Channel to be desilted.	(Y/N)	(Y/N)	(Y/N)
(ix)	Drainage channels to be cleaned.	(Y/N)	(Y/N)	(Y/N)
(x)	New drainage channel required - (indicate locations).	(Y/N)	(Y/N)	(Y/N)
(xi)	New tractor crossing required - (indicate locations).	(Y/N)	(Y/N)	(Y/N)
(xii)	New culverts required - (indicate locations)	(Y/N)	(Y/N)	(Y/N)
(xiii)	Flood protection bunds required - (indicate locations).	(Y/N)	(Y/N)	(Y/N)

7. <u>Irrigation System Management</u> (Y = 1, N = 0)

(i) What criteria is used to start the maha and yala irrigation seasons?

(ii) What kind of arrangement/organizations exists to make decision with respect to:

- Opening and closing of the tank.
- Deciding the area to be irrigated in case of water shortage.
- Water distribution (who gets, when, etc.).
- Cropping pattern and crop decision.
- Conflict resolution.
- Resource mobilization.
- Support services (seed, fertilizer, credit, tractor, pesticides).

(iii) What are the felt needs of farmers to improve water distribution practices under the tank system (in order of priority)?

(iv) Are the farmers willing to contribute to improve the tank irrigation? If so, in what way?

(v) What kind of assistance they need from the agency to improve irrigation system performance, including water distribution and crop productivity?

(vi) How serious is the problem of land fragmentation? Is land consolidation a viable proposition?

(vii) Is there a possibility to go in for agrowells in the low land areas?

(Y/N)

(viii) If yes, what kind of assistance they expect from the agency?

(ix) Is chena cultivation and homestead gardening given more importance than paddy cultivation:

(Y/N)

(x) If yes, why is it so?

(xi) What assistance from agency would make the farmers to start paddy cultivation early?

(B) WATER RESOURCES ANALYSIS

1. Catchment Area (Y = 1, N = 0)

(a) Size of the catchment area: .....ha

(b) Approximate area under recent chena: .....ha

(c) Approximate area under settlement: .....ha

(d) Approximate area under forest: .....ha

(e) Approximate area under rob knock plains: .....ha

(To be filled on the basis of participatory resource use mapping)

2. Tank Spilling and Filling History (Last 10 years)

(a) Number of times the tank spilled during last 10 years: .....

(b) Number of times the tank filled >75% full but less than <100% full: .....

(c) Number of times the tank filled >50% full but less than <75% full: .....

(d) Number of times the tank filled <50% full: .....

(e) Command area under the upstream tank (ha): .....

(f) Any other sources of water supply: .....

3. Groundwater Use

(a) No. of agrowells at present: Catchment : .....

Command : .....

Highlands : .....

(b) Highest water level observed below ground (m): .....

(c) Minimum water level observed below ground in August (m): .....

(d) Minimum water column remained in agrowells in August (m): .....

(e) Average depth of a well: .....

(f) Crops grown in: - maha .....

- yala .....

(f) Average extent cultivated per dug well: .....

4. Cultivation History

(a) Extent asweddumized under the tank during the last 10 years:

Season	Puranawela		Akkarawela	
	Extent (ha)	Crop	Extent (ha)	Crop
1994/95 Maha				
1994 Yala				
1993/94				
1993 Yala				
1992/93				
1992 Yala				
1991/92 Maha				
1991 Yala				
1990/91 Maha				
1990 Yala				

(C) MANAGEMENT ANALYSIS

The main thrust of the agronomic practices should be to ensure the best match of the sequential availability[10] of all three water resource components namely (a) rainfall (b) surface irrigation supply, and (c) groundwater supply, with the cropping patterns and cropping sequences. This will help to optimize the use of the water resource base within a cascade.

As presently practiced in the 'akkarawelas,' maximizing use of the October rainfall by 'Kekulan' sowing should be encouraged whenever it is feasible. In the puranawelas this is not feasible for several reasons. It was demonstrated as a feasible practice in the 'Walagambahu' pilot study in the early 1980s only when the essential inputs of cash, tractor hire, fertilizer, seed, etc, were provided by DOA and in time. This was done externally, but could not be continued or sustained by the farmer organization. Institutional strengthening may hopefully help to revive this for puranawelas. Reducing the period of land preparation is feasible under certain conditions in the purana fields and could be further encouraged. More than 95 percent of farmers already use shorter aged varieties and not much improvement is envisaged.

The greater scope for optimizing water use exists in the proper phasing of the 'meda' and 'yala' cropping seasons. Most small tanks do a late 'maha' or a 'meda' paddy if the maha rains do not adequately fill up the tank to a minimum level by end November. (Thus the puranawela is occupied up to March-April for this meda crop). The akkarawela on the other hand is occupied by a paddy crop up to end February or early March. OFCs can therefore start on the akkarawela only by late March with the use of groundwater from open dug wells. Or else, they will wait till the short heavy rains in early April are over and start OFC in late April to early May. Agronomic practices should be evolved to establish OFC in the akkarawela before the yala rains, thus capturing the benefit of the 150 mm of 75% probable rainfall in March-April. Or else, promote a stagger of planting dates, one before the short duration heavy early April rains and the other after these April rains.

On the highland with open dug wells, the present practice of establishing the crop (mostly chilli) with the maha rains upto January, and subsequent supplementary irrigation provides a good match with the available water resources.

There is much scope for improved on-farm irrigation practices on the yala OFC land. Proper layout of ridge and furrow method, or the raised bed or furrowed basin method could improve the on-farm efficiency even on the small plots now being used. Here again, try to understand the basins for the farmers' present practices and try to improve on them rather than testing new ideas or text book recommendations. Bear in mind that farmers have to convert these shaped

[10] Means the varying amounts available through the 'meda', maha and yala season periods taking into account the nature of their individual variability. It is assumed that the least variation is in respect of (c) groundwater.

beds, etc. back to a level liyadda for paddy cultivation in maha season, and vice-versa for yala. Therefore more rudimentary methods are appropriate.

Help farmers to evolve better methods of water delivery from the open dug well to the basins, or raised beds, or furrowed basins as the case may be. Attempt to reduce the conveyance losses in transmitting the stream and water pumped from the open dug well. Research - extension dialogue and pilot testing should be re-enforced in this field. Research officers at Maha Illuppullama are already doing something here, and should be further assisted.

A special core team of extension specialists (subject matter specialist [SMO]) educated properly on the total aspects of the cascade environment should be made available for making both rapid diagnostic assessment of problems, trouble shooting and problem solving. This should be in addition to the normal state extension service of the DOA. There needs to be a team of 3-4 persons only specializing on the cascade systems. Role of Department of Agrarian Services (DAS) needs to be clarified further. How to improve on what they are doing now.

(D) SOCIO-ECONOMIC ANALYSIS

1. Production Structure

(a)	Total area irrigated by the tank:		.....ha
(b)	Total area irrigated by dug wells:	command	.....ha
		highlands	.....ha
(c)	Total area cultivated under chena:		.....ha
(d)	Total area under home gardens:		.....ha

2. Production Constraints

Irrigated Agriculture/Tank (Y = 1, N = 0)

(a) Is the total area cultivated in maha under the tank less than existing: (Y/N)

(b) What are the reasons for low cropping intensity:

(i)	Tank does not fill.	(Y/N)
(ii)	Tank fills, but tank storage is not sufficient to feed the full command:	(Y/N)
(iii)	Tank fills, but water is lost due to bund seepage and evaporation:	(Y/N)
(iv)	Tank fills, but water gets evaporated and lost by seepage as cultivation is not begun in time:	(Y/N)
(v)	Tank fills, but water is not sufficiently used due to poor water management:	(Y/N)
(vi)	More of (ii) to (v) above (indicate):	.....
(vii)	Farmers attend chena first and as a result maha cultivation is delayed:	(Y/N)
(viii)	Farmers do not have capital to invest for maha cultivation:	(Y/N)
(ix)	Farmer reluctant to grow rice in puranawela due to difficulty in water management and crop care in fragmented lands:	(Y/N)
(x)	Paddy cultivation in maha is not profitable and hence farmers not interested:	(Y/N)
(xi)	Farmers do not want to take a risk of crop failure:	(Y/N)
(xii)	Maha paddy yield is very low:	(Y/N)
(xiii)	Chena cultivation in maha is more reliable and profitable than rice:	(Y/N)

3. <u>Irrigated Agriculture (Dugwells)</u> **(Y = 1, N = 0)**

(a) Farmers interested in having more dug-wells: (Y/N)

(b) Not many farmers have the financial ability to invest for a dug-well: (Y/N)

(c) Farmers interested in state support for digging agrowells: (Y/N)

(d) Farmers have the financial stability to invest for a dug-well but not for a pump: (Y/N)

(e) Cultivation of non-rice crops in yala in akkarawela can be done profitably if dug-wells are available: (Y/N)

(f) Cultivation of cash crops in yala in highlands can be done profitably if dug-wells are available: (Y/N)

(g) Storage and marketing for crops is a big problem: (Y/N)

4. <u>Chena Cultivation/Home Gardens</u> **(Y = 1, N = 0)**

(a) The productivity of chena lands is becoming lesser and lesser: (Y/N)

(b) The crop yields of chena lands are becoming lesser and lesser: (Y/N)

(c) The average annual income from 1 ha of chena is becoming lesser and lesser: (Y/N)

(d) The productivity of chena can be improved by adopting soil conservation techniques: (Y/N)

(e) A higher income can be obtained from chena land if a dug-well is available: (Y/N)

(f) The income generated from home gardens is less than the potential but can be improved: (Y/N)

(g) Home gardens can be used to generate high income if perennial crops are grown with soil and moisture conservation techniques: (Y/N)

(h) No extension services on soil conservation, agro-forestry, conservation farming available: (Y/N)

5. **Other Constraints** (Y = 1, N = 0)

(a) Rearing livestock is hindered by lack of pasture lands in the village: (Y/N)

(b) Markets for milk and livestock not easily available: (Y/N)

(c) Markets for non-rice crops poor: (Y/N)

(d) Quality seeds not available in time: (Y/N)

(e) Agro-chemical and fertilizer not easily available: (Y/N)

(f) A proper farmer organization not available: (Y/N)

(g) Services of an agricultural officer not available: (Y/N)

(h) Farmer organization exists but not functioning: (Y/N)

(i) Farmer organization exists but no capital available for efficient functioning: (Y/N)

(j) Many farmers need land consolidation: (Y/N)

(k) Agricultural credit facilities poor: (Y/N)

(l) Agricultural crop insurance facilities not satisfactory: (Y/N)

(m) External assistance required to consolidate fragmented and dispersed lands: (Y/N)

SWOT FRAMEWORK FOR PLANNING

INTRODUCTION

Performance and impacts of proposed tank rehabilitation program will be heavily dependent on the planning, design and implementation strategies. Therefore, a comprehensive methodology is a pre-requisite of the water resources development component of the proposed Area Development Program.

To achieve this objective the consultants suggest SWOT framework as a methodology to apply in the planning process of the water resources development component. This framework would be useful to understand most significant factors within a short time period. Therefore, consultants believe that SWOT framework would be an appropriate tool for rapid appraisal of a development project.

Main Features of the Framework

The framework has four different features: namely strengths, weaknesses, opportunities and threats. The first two features, strengths and weaknesses are mainly focused on the field study. Field studies are used to identify strengths and weaknesses that are existing. The second two features, opportunities and threats are identified based on the analysis of the strengths and weaknesses.

(g) Home gardens can be used to generate high income if perennial crops are grown with soil and moisture conservation techniques: (Y/N)

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ANNEXURE 9

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Specific Outputs of the Framework

The outputs provided by the framework to the project planners can be summarized in the following conceptual diagram **(Figure 13)**.

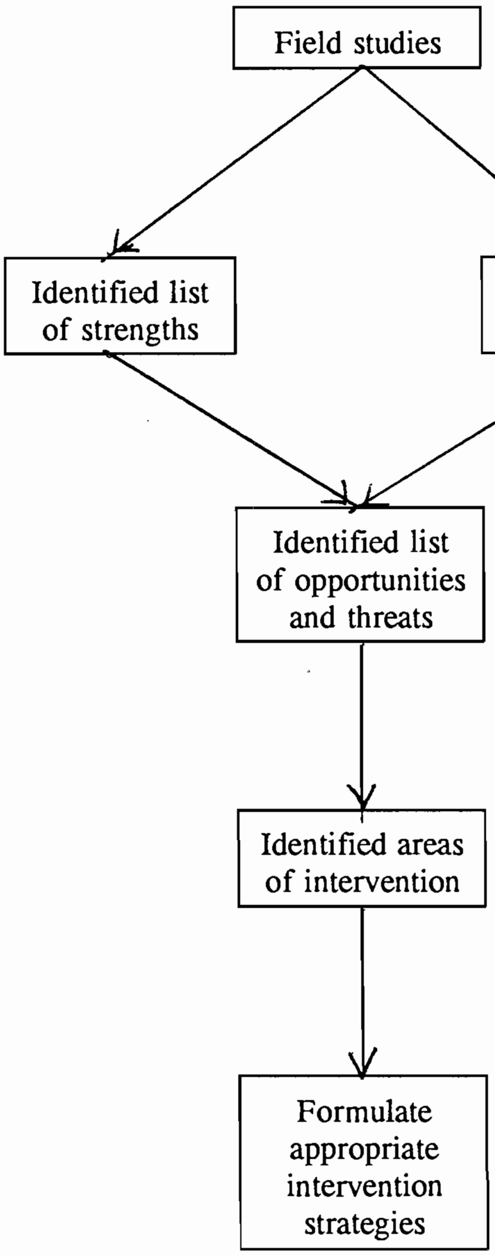

Figure 13. SWOT Framework

Approach to SWOT Analysis

Systematic and logical steps are involved in application of the SWOT framework in project planning.

<u>Step 1:</u> **Participatory Rural Appraisal**

Conducting participatory rural appraisal (PRA) sessions with representative number of project stakeholders. These sessions will lead to identifying the specific significant factors of the overall project.

<u>Step 2:</u> **Specific Participatory Rural Appraisal**

Step 1 explained above would not be sufficient to have in depth understanding on the overall issues identified. Therefore, project planners again should conduct PRA sessions focussing on overall issues to identify specific concerns of each issue. The outputs of **Step 2** would be a list of significant issues under overall issues.

<u>Step 3:</u> **Questionnaire Survey**

A questionnaire survey (QS) has to be conducted to understand the magnitude of the impact of each specific issue. There is no need to prepare different questionnaires for each specific issue identified. Hence, one questionnaire with separate sections on each issue can be administered. The questionnaires for Technical, Management, and Socio-economic analysis suggested in **Annexure 5** may be used as a guide for this purpose.

<u>Step 4:</u> **Analysis of PRA and QS Results**

This step will lead to identify the existing strengths and weaknesses. Analyses of strengths and weaknesses will lead to achieving another significant output, i.e. identification of opportunities and threats.

This process will lead to achieving the ultimate objectives of the SWOT analysis, i.e. (i) identification of areas for which interventions are required, and (ii) formulations of appropriate intervention strategies.

The four steps explained above can be shown in the following flow diagram **(Figure 14)** to understand the process.

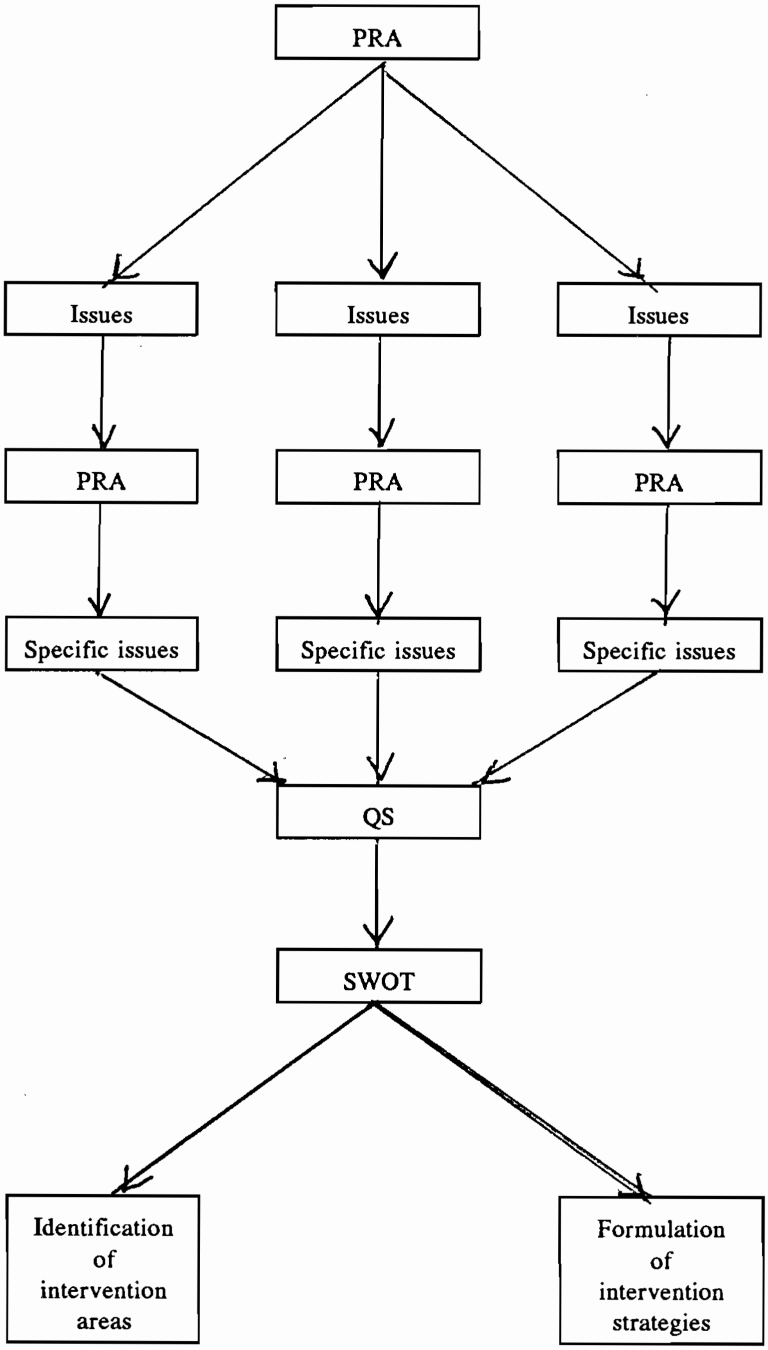

Figure 14. SWOT Analysis

The conceptual frameworks explained above can be better demonstrated by a hypothetical case study in which SWOT approach was adopted.

Case Study

Name of the small tank, Thambalagollowa located in Medawachchiya electorate in Anuradhapura district. SWOT framework was used to achieve the following objectives:

- Present level of performance of the tank in terms of physical and management aspects.

- To identify the areas both physical and management which required a development interventions.

- To formulate development strategies.

To achieve the above mentioned objectives the following activities were carried in four chronological steps.

<u>Step 1:</u> **Initial PRA**

To conduct the PRA with a representative sample of stakeholders two sessions were held with two groups. The first group consisted of farmers. Sample of the following categories of farmers were involved in the initial PRA session.

* Farmers who own more than 1 acres of land in one place in one wela in the head end and tail end area of the system.

* Farmers who own more than 1 acre of land in one place in more than one wela.

* Farmers who own less than 1 acre of land in one wela (both tail and head end farmers in the command area).

* Farmers who own less than 1 acre in several places in one wela (both tail and head-end farmers).

* Farmers who own total of less than 1 acre of land in more than one wela.

* Farmers who own land only in akkarawela not in puranawela.

However when facilitators were listing the basic characteristics of the participants it was revealed that other social characteristic such as land tenure, political divisions, etc. were included in the list of participants.

The Activities of Initial PRA with Farmers

Two major activities were carried out by the farmer groups with the facilitative guidance of the consultants.

i. Preparation of a resource map.
ii. Preparation of a social map including institutional and other social characteristics.

1. <u>Resource Mapping</u>

The facilitators assisted farmers to prepare the village map including the following physical features.

* Present status of the tank including head works and command area canal net work.

* Features in the catchment including forest existing and other development taking place including chena etc.

* The road network in the village.

* The residential pattern.

* Cropping pattern.

* Water availability in the tank and for the command area.

2. <u>Social Mapping</u>

Again the farmer group was facilitated to map the following significant social features:

i. Cultivation practices of the people.
ii. Economic levels of the community.
iii. Land tenure pattern.
iv. Yield performance.
v. Inputs used for agriculture.
vi. Social organizations including FOs and other formal or informal organizations.

vii. Assistance from the government agencies.

Based on the two exercises carried out at initial PRA with farmer group, we identified the following issues which would be significant.

Physical Issues

i. Physical condition of the tank head work is good.
ii. Canal system has problems in distributing water.
iii. Road network especially the culverts constructed disturb the local inflow to the tank during rainy seasons.
iv. Tank bed cultivation and catchment area chena cultivation is also a problem.

Social Issues (Including Management)

i. Problems in timely cultivation.
ii. Problems in cropping system.
iii. Poor yield performance.
iv. Land fragmentation.
v. Lack of unity among farmers.
vi. Lack of inputs used.
vii. Lack of assistance from the government agencies.

The second initial PRA was organized with the DAS and DOA field level officials who are responsible in providing assistance to the farmers. The officials genuinely acknowledged that at present they do not play any significant role in managing the tank or providing inputs. Therefore the consultants dropped the idea of PRA with agency personnel.

<u>Step 2:</u> **Further Studies on Issues Identified**

In order to develop comprehensive understanding on the different issues identified, again with the representative number of farmers, PRA sessions were organized. Two such issues are briefly discussed here in this report as examples.

Problems in the Canal Network

Farmer groups who represented the various social characteristics came up with the following list of specific problems regarding canal network.

i. Canals are not available for some areas in the command areas. Therefore, a group of farmers have problems in getting water.

ii. Canal bunds are dilapidated and therefore water wastes occur during the season.

iii. In some seasons although sufficient water is available in the tank. Akkarawela farmers located in the tail end areas of the command cannot get sufficient water due to insufficient canal capacity of existing canal system.

iv. Main canals do not have required structures for water distribution.

Problems in Timely Cultivation

i. In most of the seasons farmers do not start land preparation in time.

ii. They all concentrate on chena cultivation until end November, therefore rain water is wasted.

iii. The large land holding farmers although they are eager to start early cultivation have problems.

iv. Maha cultivation period is large and therefore timely cultivation in yala is a problem.

Step 3: **Questionnaire Survey**

Although farmers have pointed out significant factors under each specific issue PRA was not sufficient enough to understand the magnitude of the problems or impacts. Therefore, questionnaire survey was conducted. Specific questions to understand the degree of impact of each issue was included in the questionnaire.

Step 4: **Identification of Strengths, Weaknesses, Opportunities and Threats**

The data and information collected through PRA sessions and questionnaires were used to identify the strengths, weaknesses, opportunities and threats (SWOT) which would be useful to plan the rehabilitation process of the tank.

Matrix on SWOT

Factors	Strengths	Weaknesses	Opportunities	Threats
Physical	* Rich inflow during maha * Sufficient tank capacity * Good physical condition of head works * Sufficient land area developed	* Local catchment inflow is disturbed by the road network. * Canal net work is not adequate. * Existing canal network is dilapidated	* Water availability in the tank. * Possibility to improve canal system. * Allow local catchment inflow by changing few critical culverts which disturb the inflow to the tank.	* Catchment area chena cultivation. * Tank bed cultivation.
Social (Institutional and managerial aspects)	* Community is homogeneous. * Residences are located close to the command area. * Most of the people in the village own land * Fertile land (No salinity or any other problems)	* Farmers are not organized into groups. * A powerful group of farmers own land in puranawela as well as akkarawela. * Lack of agri-extension facilities. * There is no system for water management. * Delay in land preparation. * Low interest of group of farmers in cultivation in puranawela. * Low yield.	* Potential to organize farmers. * Potentials to motivate farmers to cultivate puranawela * Potential to improve water management practices. * Potential to bring farmers to do timely cultivation. * Potential to increase yield.	* Domination of akkarawela farmers in water use. * Farmer priority for chena. * Further fragmentation of land

Although it is not discussed here, there is a possibility to identify the degree of significance of identified SWOT by giving scores. It would provide better understanding on the factors influencing on performance.

The SWOT matrix drawn above was a basis of identification of the areas that required development interventions and also it was a basis for selecting appropriate rehabilitation strategies.

MATRIX on Areas of Intervention and Rehabilitation Strategies

Areas of intervention	Rehabilitation strategies
1. Physical * Improving canal network. * Program to stop tank bed cultivation. * Stabilizing chena.	* Participatory rehabilitation design preparation. * Developing community norms and rules to stop tank bed cultivation. * Empowering farmers to modernize chena cultivation.
* Timely cultivation. * Water Management. * Yield performance. * Organizing farmers. * Water rights to puranawela farmers.	* Institutional development component attached to physical rehabilitation package.

IMPLEMENTATION STRATEGY

The selected sub-watersheds for SCOR implementation are contiguous areas of manageable size within the main watersheds, having characteristic profiles of ecological, socio-economic and environmental features similar to that of the respective main watersheds. Several cascade systems, too, were selected as contiguous areas. Size of selected sub watersheds ranges from 200 ha to 1000 ha. Action is being taken to demonstrate an "ideal" land use pattern with due emphasis on production and protection. This "contiguous area" or "model watershed" approach of implementation would illustrate the various production - protection elements along with their intimate relationships, that will have to be incorporated in watershed management in order to produce a sustainable land and water resources base. As stated by a consultant (specialist in regional planning) who had evaluated the progress of SCOR "another interesting addition to the regional planning and implementation character of SCOR is its micro concentration on **contiguous areas** within which "every inch of surface" is carefully planned and monitored for the impacts of intervention".

In the selected sub-watersheds, participatory appraisal of the characteristics of resource uses and users as well as **current** resource use mapping were done by a 'group' comprising of : IIMI-SCOR professionals/catalysts, relevant local officials *(such as Grama Niladhari, Colonization Officers, Agric. Instructor)* and farmer/user representatives. The catalysts took the lead role in preparing the "map" and recording of information. Other group members as well as the users helped the catalysts in the identification of land holdings, consultations with users and provide information. The groups were guided and supported by senior IIMI-SCOR professionals, Divisional Secretaries, Irrigation Engineers and technical officers, Divisional Officers of Agrarian Services, Senior Officials of Forest and Agriculture Departments, etc. General objectives of a typical participatory appraisals were to:

(a) prepare a map of the sub watershed indicating individual **land holdings**, land use patterns, type and quality of vegetation, water use, drainage lines, irrigation methods etc.;

(b) develop a data base including some basic data such as: type and membership of user organizations, ownership and tenurial patterns, cropping patterns and intensities, slope category apparent degree of soil erosion, conservation practices, production and productivity, constraints to production and protection;

(c) help establish a baseline for the resource use pattern using (a) and (b); and

The SWOT matrix drawn above was a basis of identification of the areas that required development interventions and also it was a basis for selecting appropriate rehabilitation strategies.

MATRIX on Areas of Intervention and Rehabilitation Strategies

Areas of intervention	Rehabilitation strategies
<u>1. Physical</u> * Improving canal network. * Program to stop tank bed cultivation. * Stabilizing chena.	* Participatory rehabilitation design preparation. * Developing community norms and rules to stop tank bed cultivation. * Empowering farmers to modernize chena cultivation.
* Timely cultivation. * Water Management. * Yield performance. * Organizing farmers. * Water rights to puranawela farmers.	* Institutional development component attached to physical rehabilitation package.

ANNEXURE 10

IMPLEMENTATION STRATEGY

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(c) help establish a baseline for the resource use pattern using (a) and (b); and

(d) sensitize the officials of relevant government agencies/NGOs, and resource users on the importance and need for this exercise and to obtain their active participation in future work.

For this purpose, each group was provided with a line diagram/sketch map of 1:3000 scale with land marks indicating roads and streams for guidance. The group collected data and mapped each land plot of villages. Refining of the map to maintain accuracy to scale was done subsequently by the draughtsman supporting the group and the **map was used for participatory planning of resources management of that village.**

The map was digitized and linked to the computerized data base using Geographic Information System (GIS). This was repeated for each village in selected sub water basins/cascade system. For example, **Figure 15** shows the current land use (as of January 1994) by individual plot of one such village. For this particular village, a participatory resources management "mini project" was formulated with an investment of Rs.1.2 million ($24,000). The project aims to change the present **land and water use pattern to a more profitable and diversified resource use combining production and conservation using appropriate technologies/techniques, novel shared control arrangements and resource augmentation.** Novel approaches and new commercial enterprises include: cultivation of medicinal plants, fruits and vegetables in Chena (shifting cultivation areas) processing industry for medicinal plants, stabilized cropping patterns for chena and highlands, contour bunding to cover the entire area, water harvesting techniques, etc.

The planned future land use pattern is illustrated in **Figure 16.** Contour bunds and drains are being established covering the entire extent shown in this map as well as in several other pilot areas. Other activities include: planting Gliricidia Sepium as hedgerows and growing seasonal cash crops and perennial between bunds in the uplands, increase soil moisture retention using mulch (both in uplands and paddy fields), homegarden development - especially by farm women, integrated pest management, organic farming,etc. Novel modes of state-user partnerships in land and water resources use have been arranged. This mini project is backed up by SCOR with a sub-grant of approximately Rs.400,000/= (US$8000). The Banks have agreed to provide a loan 4 times larger than the SCOR grant for the user organization using the grant deposit as collateral. A Colombo based company offered a forward contract to the user organization to purchase a major portion of the expected produce under the "mini project".

Provide small grants for existing and new user groups is considered to be crucial. Such grants among other things, will enable the group to:

- Show collateral when seeking additional loans through private financial institutions;
- Develop and promote insurance schemes for new crops, conservation schemes and investments;

Figure 15 **MAHAMEEGASWEWA LAND USE - JANUARY 1994**

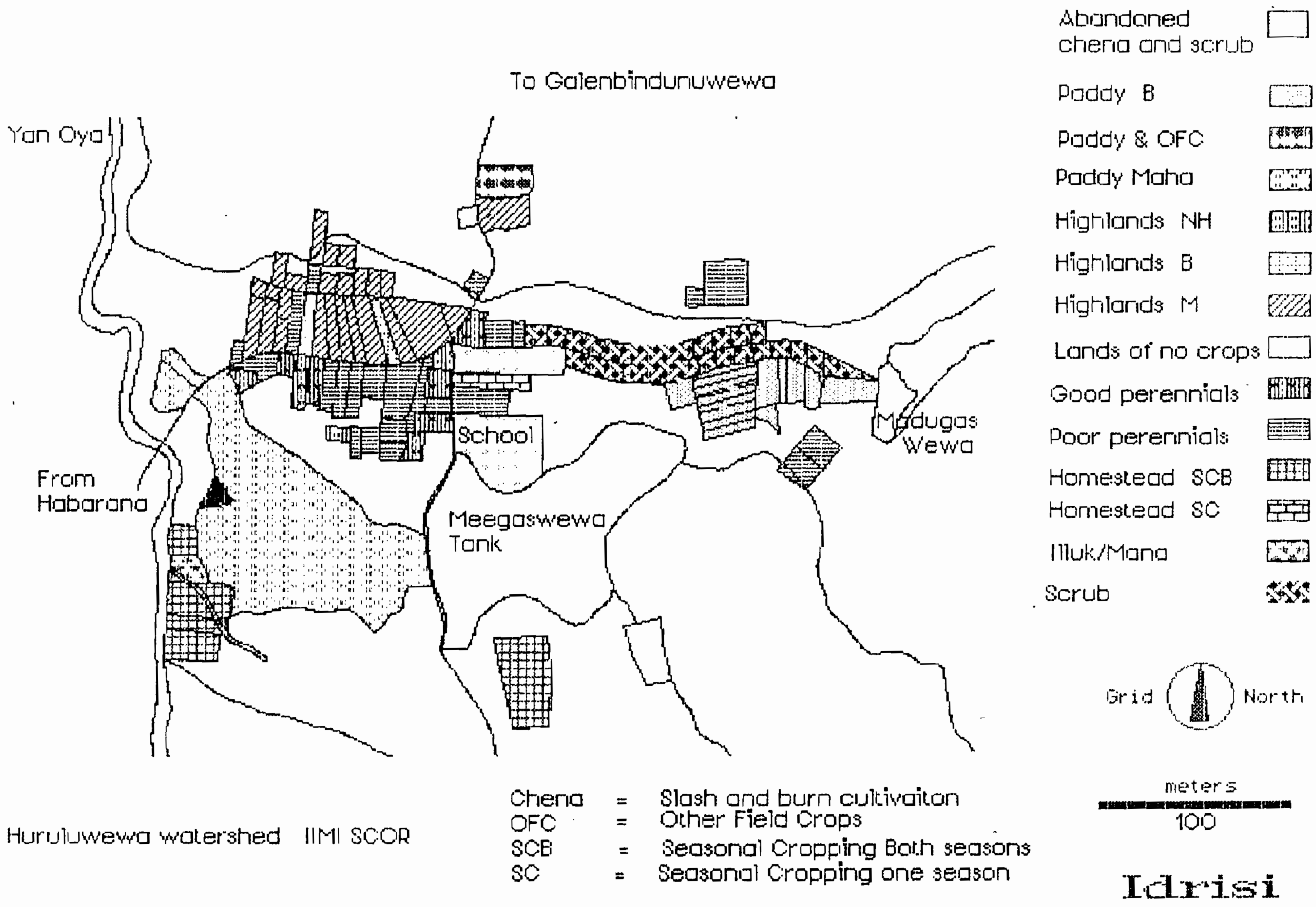
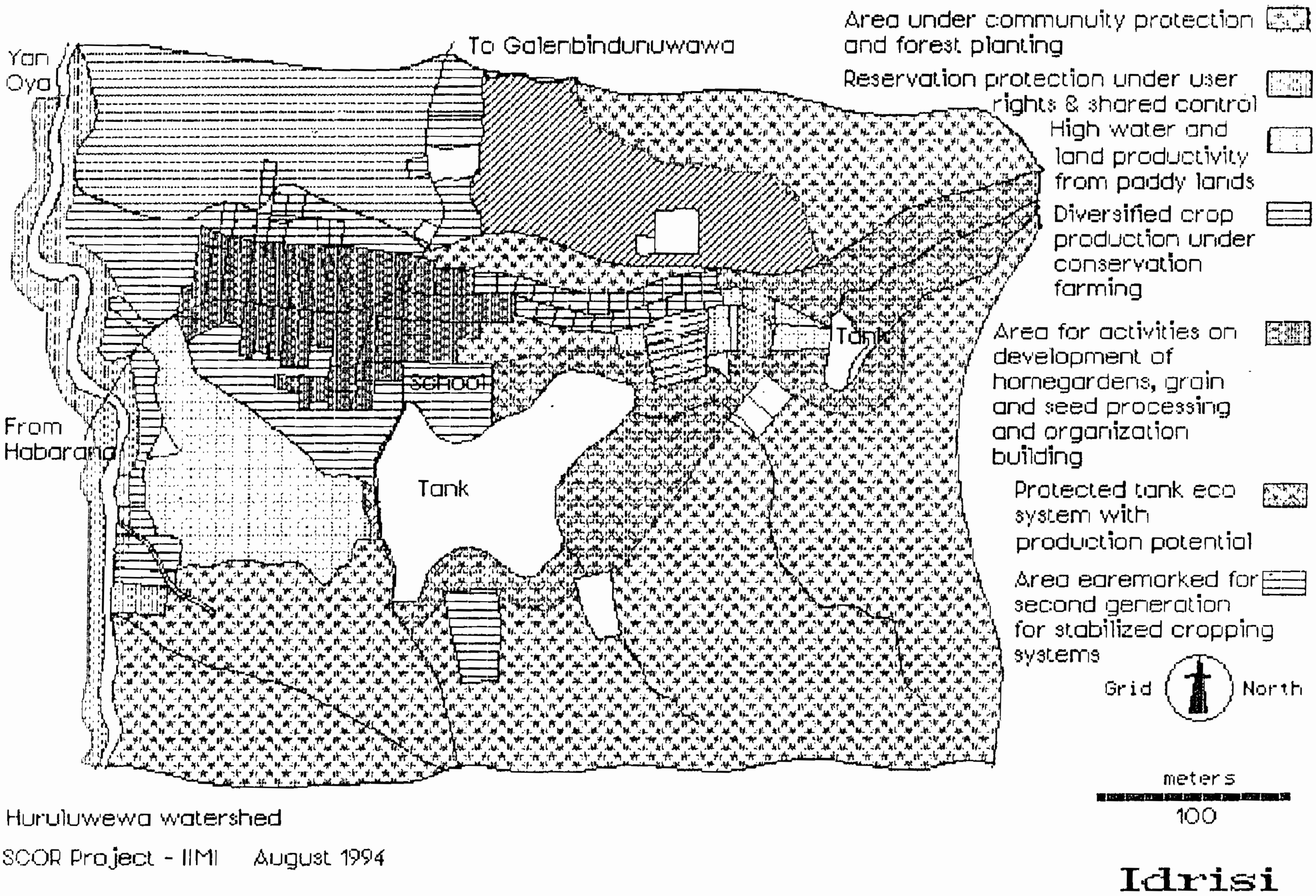


Figure 16 **PLANNED FUTURE LANDUSE FOR MAHAMEEGASWEWA**



- Construct storage facilities, markets, terraces, nurseries or other small physical infrastructure;

- Purchase equipment needed to initiate or upgrade joint enterprises to gain economies of scale and value added to their production.
- Join with other user groups to establish revolving funds for investments and/or the purchase of agricultural inputs; and

- Obtain legal, financial and other services associated with establishing user rights, small enterprises and productive ventures.

Monitoring and Evaluation

Monitoring and Evaluation (M&E) during project implementation will concentrate on performance at the interface between user groups and "support services" including those provided or facilitated by the government sector. In addition, M&E will include the necessary oversight of project activity at the other levels. Specific indicators should be identified on respective project components and data should be **gathered on each indicator** to examine/review the degree to which the **indicators of progress** have been satisfied.

Criteria to be employed in assessing the accomplishments will include:

Rehabilitation and Operation and Maintenance

- increased capacity of farmer organizations to undertake minor rehabilitation and maintenance work;

- participatory development of an inventory of functional and non-functional structures, prioritization of rehabilitation and maintenance work;

- organization of group work and its efficiency (including quality of output, financial management, etc.)

- institutionalization of participatory management of irrigated agriculture as measured by increased productivity of factors of production, improved equity etc.

Integrated Land and Water Management:

- increases in information available to user groups, and others about natural resources base, and enhanced knowledge, attitudes and behavior on resources use by all concerned;

- changes in land and water use practices;

- effectiveness of the institutional arrangements for the management of land and water resources introduced by project;

- economically viable and environmentally sound production processes.

An M&E cell will be maintained at the central project office. However, much of the M&E activity for feed back purposes will be conducted on site in a participatory and transparent mode. Data for M&E will come from several sources, including: records of self assessments by user groups at various levels, process documentation by catalysts, structured data collection by researchers (including questionnaire surveys), etc.

Self Evaluation by User Groups

User organizations will have to assume important micro watershed or cascade management responsibilities. Hence the project, before its completion, must develop and internalize mechanisms that shall strengthen management capabilities of user groups in order for them to face the challenges posed by their new management responsibilities. Thus, a process of self-assessment of organizational and production performance by user groups at different levels (and also **jointly** by user groups and implementers) is considered as an integral component of the project. By adopting self-correcting mechanisms on a continuing basis, resources user groups should attain self-reliance. Such a process of self-assessment has been successfully introduced by IIMI, National Irrigation Administration (NIA) and the Bicol University of Philippines in a major river irrigation system in Bicol, Philippines.

ANNEXURE 11

RESPONSE AND COMMENTS TO THE OBSERVATIONS OF IFAD ON THE IIMI DRAFT IEE REPORT

Mr. Brian C. Baldwin, Project Controller, Sri Lanka, Asia Division of IFAD sent his observations on IIMI Draft IEE Report on **'Guidance Package for Water Resources Development Component of Small Tank Systems'** by a letter through facsimile transmission on 24 November 1994. This IEE report is the previous draft of the current final consultancy report carrying the same title, which has been enriched with additional information and annexures and suitably amended on the basis of the above comments of IFAD. This annexure provides our response and comments to the above comments made by Mr. Brian Baldwin of IFAD. (Paragraph numbers indicated below in this Annexure refer to the unnumbered paragraphs of the above letter sent by Mr. Baldwin. The study team has taken the liberty of numbering the paragraphs of this letter for convenience for reference. Under the titles **'Comment'** under each para that follows, the specific comments of IFAD's letter have been restated, whenever required, for clarity).

Paras 1 and 2: No Comments

Para 3: This consultancy work is to look at Water Resources Development Component of the Initial Environmental Evaluation (IEE) undertaken by IFAD for the NCP of Sri Lanka. Our direct concern in this work is to look at the development of surface and groundwater resources at the sub-watershed (cascade) level as a primary unit and then to move to individual tank/village level at a next level. For planning and management of land and water resources in a holistic manner, working from whole to part is much easier than vice-versa. On the other hand, implementation will be much easier from part to whole.

Para 4: **Chapter 1** of the previous draft IEE report has been extensively revised and the text is suitably amended. The **Chapter 1** of this final IEE report is completely new. It includes definitions for terms 'cascade' and 'cropping intensity' too, as requested by IFAD in para 7 of the letter.

Para 5, Sub-para (i):

Refer to **Annexure 12** for the suggested studies that will have to be carried out by ADB, from 1995 onwards, in the broader context of cascade studies.

Para 5, Sub-para (ii):

Comment: Assessment of the likelihood and significance of negative impacts arising from water development components of the proposed project.

Response: This will be carried out through the simulation model developed under this consultancy. The simulation model looks at the water development component not only at the tank level but also its impact (both positive and negative) of water development on the upstream and downstream of the tank proper, i.e. at the cascade level. When we talk about the negative impact of water development at the tank level, a number of issues can be considered; for example issues such as:

- influence of upstream water resources development (tank rehabilitation/restoration) on water availability and cropping intensity of downstream tanks.

- flood mitigation due to increased water conservation.

- land submergence due to water conservation.

- dry weather flow reduction in natural streams.

- groundwater recharge and build-up.

- waterlogging and salinity problems.

- deprivation of non-agricultural water uses.

- health hazard due to mal-distribution of water among the tanks.

When we talk about upstream and downstream impact, one can again analyze the reduction in dry weather flow and is impact on flora and fauna, impact on agricultural production, land submergence ont he upstream side, inequity in water use between upstream and downstream users, impact on groundwater quantity and quality.

The proposed simulation model would provide the spatial and temporal distribution of water within the cascade systems which would then form the basis for analyzing the impact of such water distribution storages on the issues listed above.

Comment: Definition of trends in groundwater quality and quantity, indicating reasons for change if possible, ways in which negative change can be minimized and additional analytical data needs.

Response: Refer to **Annexure 6** on 'An Analysis of Groundwater Resources, its Estimation and Abstraction Through Agrowells in Anuradhapura District'.

Comment: Determination of groundwater resources from available data, indicating where these are inadequate and the areas most suitable for further development. Indication of particular features of the groundwater system which might limit the extent of development.

Response: A typical cross section of a hard rock aquifer is shown in **Figure 17**. Generally one would expect a lithology indicating top soil, weathered zone, fractured and fissured zone and base rock. However, in many places one would see only top soil and base rock interspersed with either weathered zone or fractured zone or nothing in between. Under these conditions, groundwater availability will be limited. Identifying a site which has favorable geological and geo-hydrological conditions through geologic, resistivity and an photo survey is necessary to site a favorably producing well.

Para 5, Sub-para (iii):

Comment: Selection of typical sub-watersheds

Response: In Section 4 of **Annexure 1** titled 'General Characteristics and Proposed Typologies of Small Tank Cascade Systems', the method of selection of the three typical sub-watersheds has been explained. It states that initially 20 small tank cascades were delineated and from this five were selected on the basis that these are considered to be representative of the range of cascades of Anuradhapura District.

Of these five cascades, three were intensively studied, namely Tirappane, Mahakanumulla and Ulagalla, because there had been prior studies conducted on these by IIMI and the Department of Agriculture (see references). The other two cascades, namely Gangurewa and Timbiriwewa were less intensively studied in order to capture the range of characteristics of the cascades.

Comment: upstream-downstream linkages of cascades and about frequency of spilling of the tanks studied.

Response: This comment is in relation to page 4 (para 12 of Section 2) of the previous draft IEE report. A separate para (para 13 of Section 2) has been added in this final report to clarify this aspect.

It has to be noted that the tanks studied are not from the same cascade and were selected from different cascades. It was so because the tanks which had undergone rehabilitation by previous rehabilitation projects were selected in order to identify the drawbacks of previous rehabilitation approaches. Also, tanks for which rehabilitation design notes, design specifications and drawings as well as data such as catchment area, water spread area, command area, depth-area-capacity relationships were picked up for obvious reasons. (The Section 2 of the previous draft IEE report as well as this final IEE report have been prepared mainly on this study).

However, the frequency of tank spilling and tank filling of the tanks does not imply that there is no or little hydrological and human interactions between individual tanks of a cascade. Low frequency of tank spilling and tank filling may have resulted from restoring tanks in the cascade which had been previously abandoned and non-working or from raising tank bund to improve the capacity of some tanks in the cascade form time to time, without understanding and considering the overall hydrology of the cascade. It may also result due to low seasonal rainfall too. On the other hand, even though the tanks do not spill or fill to its full capacity, significant hydrological interactions are taking place between the tanks. For an instance, in a normal rainfall year, even though each individual tank of the cascade do not spill, the drainage return flows to a tank from lowland rice cultivated area of the upstream tank is a significant component of the tank water balance of the downstream tank. On the other hand, in years of excess rainfall, when the tanks begin spilling, the safety of each individual tank and crops grown under the tanks of a tank cascade depends on careful operation of the entire cascade. Also, there is significant subsurface flow from tank to tank in a cascade. Thus, a rapid study of assessment of the interactions between tanks in a cascade is very relevant.

Para 5, Sub-para (iv):

The proposed implementation strategy is not heavy, and in-fact, cost-effective. It relies mainly upon team work of relevant agency officials at field level, Divisional level and Provincial level. The proposed working teams at all levels in the implementation strategy are heavily drawn from the relevant government agencies, NGOs and farmer organizations without additional costs. What has been suggested is a new day to day working mode with the available agency officials at all levels, and some externally recruited IOs (Catalysts) and a multidisciplinary Technical Assistance Team. The additional elements required are the catalysts/IOs to strengthen the field level and the Technical Team at provincial level. If funding for the proposed TA team is a constraint, experts of the relevant disciplines may be drawn from the government service to work in the TA team on secondment basis.

The **Chapter 6** on 'Implementation Strategy' has been slightly modified to highlight the cost-effective nature of the proposed implementation strategy.

Almost the same implementation strategy is being adopted in the SCOR project too. Unlike many other efforts on land and water based development, SCOR project has already proved to be cost-effective. In spite of its 'additional elements' such as catalysts and a multidisciplinary team of professionals, the output has already exceeded the costs. There is a built-in mechanism for institutionalization of project strategies and approaches and the 'additional elements' will be gradually phased out or absorbed by user organizations, without a burden to government budgets. For example, catalysts, depending on the need for their continued presence (to augment the profits of farmer organizations) will be absorbed by the farmers organizations later. Hence, the sustainability of 'project-driven success' after the completion of the project may not be questionable.

Para 6: The words 'catchment area,' 'watershed,' and 'cascade,' have been described in Chapter 1 of this Final IEE report.

Para 7: The cropping intensity (CI) is now defined and explained in Chapter I. The method used for computing weighted cropping intensity may appear cumbersome; it is equivalent to defining

$$CI = \frac{\text{total irrigated area under cascade}}{\text{total command area of cascade}}$$

However, obtaining the weighted CI from individual tank CI has certain physical significance. Computationally, the method suggested by the reviewer is simple and can be used.

Para 8 and 9:

The argument put forward by the reviewer has a flaw in that tank waterspread area and command area are not considered explicitly. If both tank waterspread area and command area are one and the same, then the argument given by the reviewer in para (8) holds good. However, in the example worked out tank waterspread area is 100 ha whereas lowland paddy area is only 40 ha. In view of the comments given under paras (8) and (9) of IFAD letter, the section under concluding remarks of the Annexure 6 of the previous draft IEE has been revised and rewritten now. Please refer to **Annexure 7** on 'A Numerical Example for Computing A Number of Agrowells under A tank' of this final IEE Report.

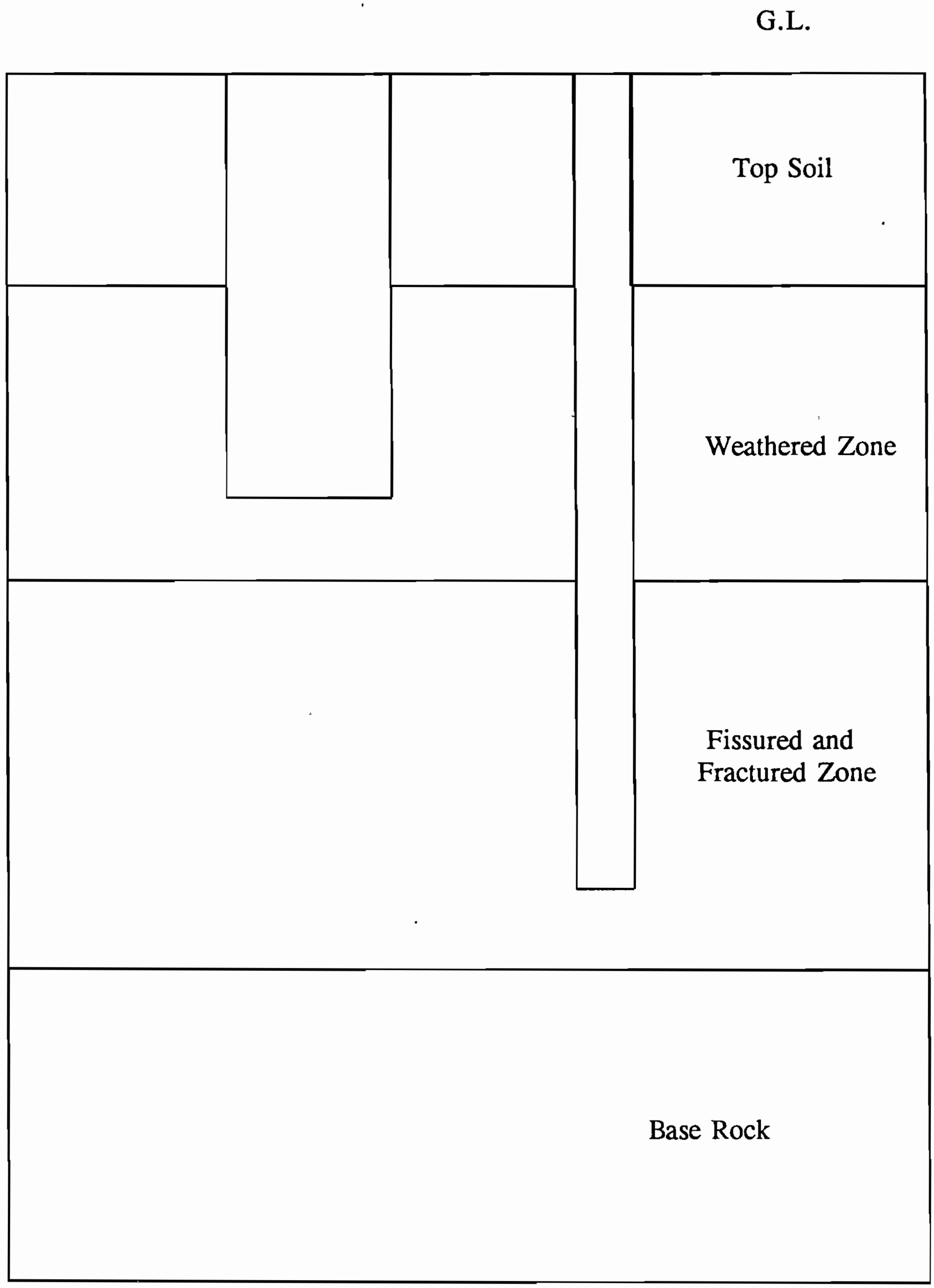


Figure 17. A Typical Cross Section of Hard Rock Aquifer

FURTHER CASCADE RELATED STUDIES TO BE CARRIED OUT BY ADB

Further studies have to be carried out at the cascade level in the following areas:

1. Systematic methodology for mapping of sub-watersheds with their physiography, geomorphology, land use and hydrology.

2. Characterization and understanding the subsystem behavior based on physical and socio-economic considerations.

3. Refinement of the simulation model proposed in this report and its application for different development scenarios.

4. System monitoring of surface and groundwater resources (both quantity and quality) in selected sub-watersheds.

5. Testing of technical, water resources, management and socio-economic analysis suggested in the guidance package for tank rehabilitation and its refinement.

6. Refining the tank selection and rehabilitation investment criteria suggested in this guidance package using a larger sample of tanks.

7. Testing seasonal planning strategies that will make the best use of available rainfall in chena and irrigated commands, considering chena and tank as the composit agricultural production system.

8. Identification of areas more suitable for groundwater development through geologic and air-photo surveys and resistivity tests.

9. Tank water balane studies to refine and understand catchment rainfall and runoff relationships in relation to different catchment land uses and other parameters such as catchment pre-saturation water requirements, direct rainfall on tank bed, tank losses, drainage return flow coefficients, etc.

10. Studies on catchment soil erosion and tank siltation with special empahsis on developing cost-effective techniques for desilting minor tanks to improve their agricultural potential and other environmental socio-economic benefits.

11. Testing appropriate land and water conservation techniques that would strike a desirable balance between water conservation in the tank catchments and catchment runoff to tanks.

12. Developing strategies for land consolidation under minor tanks.