Research Report

Rehabilitation Planning for Small Tanks in Cascades: A Methodology Based on Rapid Assessment

R. Sakthivadivel, Nihal Fernando,
and Jeffrey D. Brewer

International Irrigation Management Institute

Research Reports

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Research Report 13

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The work described here was funded by the International Fund for Agricultural Development and the Asian Development Bank. C. R. Panabokke, K. Jinapala, and C. M. Wijayaratna contributed substantially to the field and other studies underlying this work. The authors would like to thank David Seckler, Chris Perry, T. M. S. Pradhan, David Molden, Ian Makin, and Brian Albinson for helpful and perceptive comments on earlier drafts of this report.

Sakthivadivel, R., N. Fernando, and J. D. Brewer. 1997. *Rehabilitation planning for small tanks in cascades: A methodology based on rapid assessment.* Research Report 13. Colombo, Sri Lanka: International Irrigation Management Institute.

/ irrigation systems / rehabilitation / tank irrigation / small-scale systems / reservoirs / conflict / farmer participation / river basin development / water resources development / Sri Lanka /

ISBN 92-9090-345-0
ISSN 1026-0862

Editor: Kingsley Kurukulasuriya; *Consultant Editor:* Steven Breth; *Artist:* D. C. Karunaratne; *Typesetter:* Kithsiri Jayakody; *Publications Manager:* Nimal A. Fernando.

Contents

Summary

This report argues that irrigation system rehabilitation planning must take place within a basin context. That is, the impacts of system improvements on other users in the basin must be assessed to avoid creating or aggravating discord over water and to ensure that investments in water resources development give the expected benefits. However, in many places the needed hydrologic database for each basin does not exist.

The report describes a methodology developed to plan the rehabilitation of small tank (reservoir) systems in the dry zone of Sri Lanka, an area where the hydrologic database is deficient. The method makes use of data from three sources—topographic maps, rapid assessments, and farmers—to assess the hydrology of tank cascades (subbasins). Data are gathered from farmers at participatory sessions that provide a basis for planning the improvement of specific irrigation systems.

The key value defined is the outflow from the cascade under present conditions. This value determines the types of irrigation system improvements that can be permitted within the subbasin. In addition, the method provides a means for evaluating individual irrigation systems to determine the types of improvements permitted to avoid conflicts over water within the basin. By involving farmers in the assessment and planning, the method also lays a foundation for farmer cooperation in carrying out the rehabilitation. Finally, the method permits, indeed requires, the use of additional nonhydrologic criteria for selecting irrigation systems and evaluating rehabilitation plans. The methodology was field-tested in Sri Lanka's dry zone in 50 tank cascades that cover an area of 25,000 hectares and have 700 minor and medium-size tanks.

This method can be applied in similar situations in India and elsewhere. With slight modifications, it can also be used for evaluating water resources development projects in many river basins dominated by small-scale irrigation systems.

Rehabilitation Planning for Small Tanks in Cascades: A Methodology Based on Rapid Assessment

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Introduction

This report presents a methodology for planning the rehabilitation and improvement of small-scale irrigation systems within the context of the water basin when information on hydrology and water use is inadequate. It was developed for planning the rehabilitation and improvement of small tank systems in the dry zone of Sri Lanka. The methodology may not only be useful to those undertaking irrigation rehabilitation projects in similar circumstances, but we believe it also can be extended to water resources planning in many other circumstances.

Need for a Basin-Wide Context for Planning Irrigation System Rehabilitation

Over the past 20 years, the rehabilitation and improvement of irrigation systems have been a major type of investment in water resources management systems. Rehabilitation and modernization projects have been undertaken not only to spread the benefits of irrigation to more agricultural land but also to improve water use efficiency so that water can be withdrawn from agriculture for other uses. These projects have been important because irrigation is by far the largest user of fresh water, consuming two-thirds of all fresh water used by human beings (Postel, Daily, and Ehrlich 1996).

However, the well-documented inefficiencies of individual irrigation systems do not imply that fixing irrigation systems will mean more water to go around (Seckler 1996; Keller and Keller 1995). In many cases, downstream reuse of water “lost” in one irrigation system ensures that the overall efficiency of water use within the water basin is quite high.

This finding has two important implications for planning irrigation system rehabilitation and modernization projects. First, improving an irrigation system so that a greater portion of the water entering the system is consumed by the crops may result in taking water away from downstream users. That is, a project may simply result in shifting the area irrigated from one place to another, which could create or aggravate conflicts over water.

Second, improvements to a downstream system may give little or no net benefits if improvements or changes upstream affect the available water.

To avoid these problems, individual projects should be planned within the context of the whole river basin so that downstream effects can be determined. However, in many places, basin-wide planning is hampered by the lack of detailed information on basin hydrology and on the present uses of and claims on water.

Basic Elements of the Methodology

Donors and governments are concerned with making the best use of their limited funds. Given the large number of irrigation systems that could be improved or rehabilitated, a procedure for selection is essential. Once selected, a preliminary specification of work to be done is needed for planning purposes. Therefore, we set out to devise a methodology for evaluating irrigation systems as candidates for rehabilitation and for making a preliminary study of rehabilitation and improvement needs. We were particularly concerned that these studies take cognizance of the hydrology of the basin in which each candidate irrigation system lies.

Each irrigation system is but one element in the full collection of water users within a water basin. The problem is to find a way to evaluate the effect of improvements to one irrigation system on others. Clearly, if there is a large body of hydrologic data for the water basin, including knowledge of water flows among the various parts of the basin, the effects of any one change can be determined through mathematical models. If, however, adequate data are not available, other means can be adopted.

We propose that improvements to multiple irrigation systems within a single basin can, at least for small basins, be evaluated through the following general procedure:

1. Assess the overall surplus of water within the basin by estimating and evaluating outflow from the basin.
2. Analyze the availability of water, the agricultural performance, and the rehabilitation needs for each irrigation system that is a candidate for improvement.
3. Select rehabilitation proposals on the basis of general rules:

   - If the basin water surplus is less than the set criterion, do not approve any proposal that would increase the amount of water extracted by any one system.

   - If the basin has a water surplus, then consider use of the surplus to augment the water available to individual systems that have too little.

   - If an individual system has sufficient water resources but poor agricultural performance, focus on repairs and management improvements.

   - If an individual system has sufficient water resources and good agricultural performance, little improvement is needed. However, in a surplus basin, consider expanding the irrigated area if suitable land is available.

The keys to this procedure are the methods by which basin and irrigation system hydrology can be assessed effectively and quickly in the absence of a reasonable database. Most important is the estimation of the basin outflow. In this report, we use the example of selection and evaluation of rehabilitation proposals for small-scale irrigation systems in Sri Lanka to show methods by which basin and system hydrology can be assessed rapidly and effectively in the absence of a good database.

Improvement of Dry Zone Tank Irrigation Systems in Sri Lanka

Irrigation in Sri Lanka

The history of irrigation development in Sri Lanka goes back to over 2,000 years (Brohier 1934; Seneviratna 1989). Irrigation developed hand-in-hand with rice growing; rice was, and is, the staple food. Today, Sri Lanka has more than 17,000 functioning irrigation schemes covering approximately 500,000 hectares. About 99 percent of these schemes irrigate less than 80 hectares each and are classed as "minor" irrigation schemes. In total, minor schemes irrigate about 150,000 hectares.

Sri Lanka is conventionally divided into two climatic zones, the wet zone and the dry zone. The wet zone, the southwest third of the island, gets over 2,000 millimeters of rain annually. The dry zone, the remaining two-thirds of the island, gets less than 2,000 millimeters.

The country has two farming seasons. *Maha* (the wet season) stretches from October to February when the northeast monsoon brings heavy rains to the whole island. *Yala* (the dry season) runs from April to July when the southwest monsoon brings heavy rains to the wet zone and light rains to the dry zone.

Operation of Tank Cascades

In the dry zone, most of the minor irrigation systems are tank systems; that is, they are based on small reservoirs. These tanks fill with the maha rains. From the tanks, water is taken to the fields through earthen channels. Rainfall, although relatively high (over 1,000 mm/year), is quite variable and soils in the dry zone are shallow and porous. As a consequence, many tanks fill only in about 3 out of every 5 years. Not surprisingly, many farmers depend on rainfed upland farming as well as on irrigated farming in the tank commands.

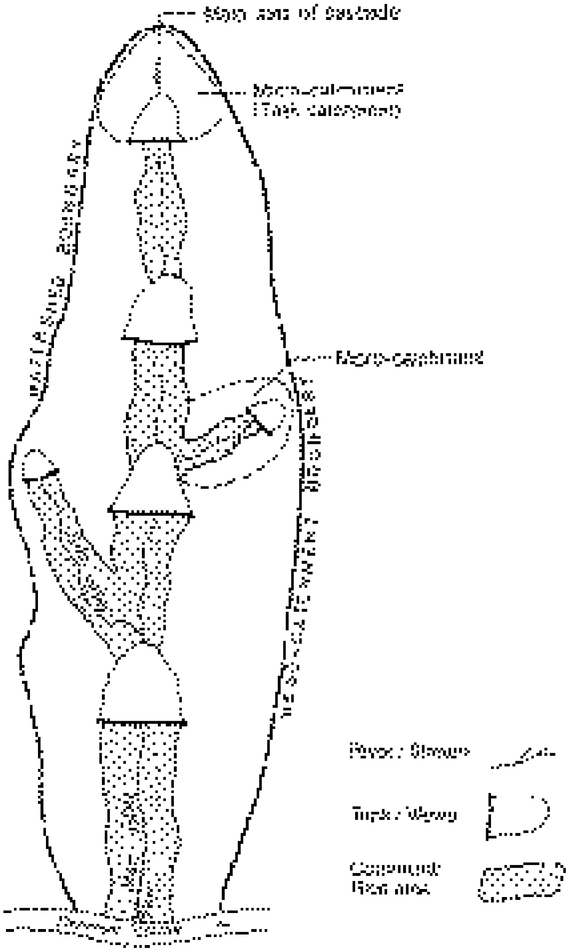
Dry zone tank irrigation systems are generally arrayed in cascades. A tank cascade is a connected series of tanks organized within the meso-catchment of the dry zone landscape. It drains to a common reference point of a natural drainage course, thereby defining a sub-watershed unit with a definite watershed boundary. It stores, conveys, and utilizes water from first- or second-order ephemeral streams (Madduma Bandara 1985; Sakthivadivel et al. 1996). In these small valleys or meso-catchments, the surface water flows are intercepted by small man-made earthen bunds to create reservoirs; these generally increase in size as one moves down the valley. Each small tank has its own catchment area. In addition, excess water flowing from one tank in the cascade is captured in the next tank downstream. When farmers draw water from one tank to irrigate land, the irrigation return flows are captured in the next downstream tank.

A schematic representation of a tank cascade showing the hydrologic interlinkage of tanks is given in figure 1. Cascades have 2 to 25 tanks; in our study area, the average was 14 tanks per cascade.

Villages control most tanks. Generally, each village in the dry zone will have a village tank that is used for domestic needs as well as for irrigation. There may be other, smaller, tanks within the jurisdiction of a village. In a classic study of a community in the dry zone, Leach (1961) describes the close association of kinship, land tenure, and irrigation management that provides the basis for village management of such tanks. On the other hand, there are no means for the coordination of water management among villages (Samad 1995); there are no cascade-level management entities. Instead, farmers under each tank have developed various means of adapting their irrigated area to the highly variable water supplies (Leach 1961; de Jong 1989). Today, the government of Sri Lanka is attempting to create village-based farmer organizations to manage the tanks and to take on other agricultural functions.

The total setting of the small tank village from the point of view of its position in the landscape and the principles of land and water use that had been understood and practiced by the early settlers are best brought out by Abeyratne (1956) in his discussion of some of the basic features of traditional dry zone agricultural systems. Tennekoon (1986) provides additional explanation of tank cascades and their traditional uses.

FIGURE 1.
A typical tank cascade.



Hydrology of Tank Cascades

Past scientific studies on small tank systems were confined to individual small village tanks rather than to tank cascades. Kennedy (1933) observed that no prior attempt had been made to collect scientific statistics of minor irrigation works or to apply scientific principles to their repair and improvement. Kennedy proposed four main criteria for the selection and improvement of minor tanks. These required the collection and analysis of meteorological and hydrologic data, a thorough investigation of the topographical and geological site conditions, an evaluation of the benefits in relation to the costs, and an assessment of the attitude of the farmers towards the proposed improvements. He also outlined procedures to be adopted in estimating the catchment area, yield, tank capacity, and spill discharge for the small village tanks. Arumugam (1957) consolidated and extended Kennedy's approach. Ponrajah (1982) dealt with a small (up to 50 square kilometers) catchment analysis that was complementary to the works of Kennedy and Arumugam. Hydrologic analyses of small tanks for purposes of rehabilitation planning are currently carried out following Ponrajah's guidelines for individual tanks.

Somasiri (1979) conducted an in-depth study of water balance of a small tank with field measurements in Anuradhapura District for four consecutive seasons. The tank has a water surface area of 30 hectares at full supply level and a storage capacity of

35.8 hectare-meters. Its catchment area is 115 hectares and the irrigated command area is 13 hectares. Somasiri observed that the catchment runoff during the maha season varied from 25 percent of rainfall in a very wet maha season compared with 5 percent in an average maha season. On the basis of the above values, the total yield per square kilometer of catchment in an average maha season would be about 4.8 hectare-meters, while in a wet maha season it would be about 24 hectare-meters. He also observed that for the maha season, about two-thirds of the tank storage derives from runoff and one-third from direct rainfall on the tank water surface.

In further studies, Somasiri (1992) showed that small tanks with more than 10 hectares of catchment for each hectare-meter of storage capacity can attain full supply level for 40 to 75 maha seasons out of 100 and at least three-fourths supply level for 50 to 75 maha seasons out of 100. Therefore, the irrigation potential of minor tanks could be considered favorable when the catchment area per hectare-meter of capacity is more than 10 hectares.

Dharmasena (1991) reports that the catchment area of a tank absorbs a significant amount of rainfall for initial soil saturation before it generates any productive or useful runoff and that around 150 millimeters of rainfall are required during the early part of the maha season before runoff commences. This value is in conformity with the moisture-holding capacity of the Reddish Brown Earth soils, which require around 150 millimeters of rain to become moistened to field capacity.

A shift in research emphasis from single small tanks to tank cascades followed Madduma Bandara's (1985) study of tank cascades in the dry zone of Sri Lanka. His approach emphasized the treatment of the total tank cascade rather than the individual tanks within a cascade as the more logical focus for any study of small tank systems.

Itakura carried out the first water balance study for a whole cascade (Itakura and Abernethy 1993; Itakura 1994) in the Tirappane cascade in Anuradhapura District. The Tirappane cascade is made up of four minor tanks along the main valley and two minor tanks on a side valley. In a water balance study conducted over two maha seasons and two yala seasons, measurements were made on rainfall, water issues from the small tanks, drainage flows from the command area, water level in the tanks, and evaporation. It has been observed that for the two maha seasons the average runoff was 30 and 12 percent of the rainfall, respectively, and for the two yala seasons it was 10 and 4.5 percent, respectively. Itakura also measured drainage return flows from upstream to downstream tanks for the total cascade. For maha seasons, drainage return flows averaged approximately 23 percent of the tank storage for the tank located midway along the main valley, 29 percent for the tank located at the lowest end of the main valley, and 12 percent for the tank located at the lower end of the side valley. Return flow values for yala seasons were zero.

Although these studies have generated useful hydrologic information on small tanks, they are limited in extent and scope. There has been no systematic attempt to collect and organize the hydrologic data on the tank cascades for any portion of Sri Lanka's dry zone.

Small Tank Rehabilitation

Because of the importance of irrigation in Sri Lanka, improving irrigation facilities has long been a popular means of rural development. In the dry zone, there have been numerous small tank restoration and rehabilitation projects including special donor-funded projects, components of integrated rural development projects, and efforts by several nongovernmental organizations.

Local histories show that individual tanks within a cascade have come into existence at different times (Brow 1978). Apparently, water supply adequacy has not played a major role in the siting of the tanks. Thus although some tanks have sufficient storage capacity and catchment area to supply adequate water, others do not have enough catchment potential or tank capacity to satisfy the requirements of the designed command area. The inability of a farming community to capture adequate water often results in persistent demand for augmentation of water supply through enlarging tanks or by taking water from other tanks, from diversions from streams, or from drainage channels. In addition, rising population is leading to increasing demands for water for irrigation and domestic uses in the dry zone.

Not surprisingly, therefore, small tank rehabilitation and improvement projects generally aim to:

- repair the distribution network to let the farmers improve the efficiency of water distribution and expand the irrigated area
- increase water availability by raising or extending the tank bund, or both, by augmentation from other tanks, or by other means

Altering the hydrology of one or more tanks by increasing storage capacity, expanding irrigated command area, or by diverting water elsewhere from the cascade, changes the cascade hydrology. If the cascade has more water than is demanded, the effect of altering the tank hydrology may not have significant downstream impact. But if water is limited in relation to total demand, there may be a serious effect on the water available to downstream users. In the worst case, improving an upstream tank takes away water from a downstream tank (for an extreme case see Kariyawasam, Jayananda, and Kularatne 1984). Improvements to one tank can also affect other water users by inundating lands in the command area of the tank immediately upstream. Also, because tank hydrology strongly influences groundwater, wells below tanks consistently have more groundwater than other wells, even in the driest parts of the year. Changes in water availability in tanks can thus affect the availability of groundwater for irrigation and other purposes.

For these reasons, planning the rehabilitation or improvements of any tank system requires assessing and understanding the entire hydrology of the cascade before any intervention to any tank in the cascade is contemplated, especially when water is becoming scarce. Unfortunately, with a few exceptions, there are no data on cascade hydrology in Sri Lanka. Neither the government nor others have attempted to systematically collect hydrologic data on small-scale irrigation systems, including the tank cascades.

Failure to consider cascade hydrology had been detrimental to small tank rehabilitation projects. The rehabilitation of numerous small tanks in Sri Lanka's dry zone has been strongly criticized for poor benefit-cost ratios and other flaws (Abeyratne 1990; Dayaratne 1991; Dayaratne and Moragoda 1991; Dayaratne and Wickramasinghe 1990; Ekanayake, Navaratne, and Groenfeldt 1990). The major problem has been poor supply of water to the tanks. Without additional water, tank rehabilitation has often failed to increase cropped area or cropping intensity. In large part, the disappointing record of past small tank rehabilitation efforts stems from poor understanding of tank hydrology, lack of data, and the variability of water supplies in the dry zone.

To improve the planning of tank rehabilitation projects, the key need is to obtain data on the amount of water not currently used within the cascade—the cascade water surplus. The adoption of a cascade-based holistic approach to water management and small tank rehabilitation has been hindered by lack of data on, and a clear understanding of, the hydrology and the physical characteristics of tank cascades; by the absence of field-tested methodologies, tools, and criteria for evaluating the water surplus of cascades; and by failure to link planning of rehabilitation interventions with cascade water surplus and with suitable management institutions.

At present, the tank rehabilitation planning process adopted by local irrigation agencies does not include a proper assessment of the potential of surface water and groundwater, recharge, and the possibility for harnessing groundwater to complement rainfall and tank water to increase overall cropping intensity.

Origins of the Methodology

The methodology described here was developed specifically for small tank rehabilitation project planning in Anuradhapura District of the North Central Province in Sri Lanka. The methodology was developed as part of IIMI's participation in two studies for the International Fund for Agricultural Development (IIMI 1994; IIMI 1996a) and one for the Asian Development Bank (IIMI 1996b). An earlier stage in this development is documented in Sakthivadivel et al. 1996. These efforts are part of two interlinked projects, one funded primarily by IFAD and the other funded primarily by ADB. The projects are designed to help develop the natural resources of the North Central Province in a sustainable way.

To illustrate the methodology, data from IIMI 1996a are used. This work was carried out in 1996 and was limited to Anuradhapura District, the larger of the two districts in the North Central Province. The primary data used for this study came from field work carried out by IIMI. Secondary data were obtained from the Department of Agrarian Services and the Central Irrigation Department of the Government of Sri Lanka and from the North Central Province Irrigation Department.

Anuradhapura District is situated entirely in the dry zone and is characterized by the existence of a large number of small tank cascades. Although the mean annual rainfall is around 1,500 millimeters, the 75 percent probability value is approximately 800 millimeters. This value is a more realistic indicator of dependable rainfall, because of the high variation of the annual rainfall. The maha season, the main rainfall season, has a 75 percent probable rainfall of 650 millimeters. The yala season has a 75 percent probable rainfall of 150 millimeters. From late May to September, the district experiences a 4- to 5-month dry season with strong desiccating winds. Evaporation rates during this period are around 7 millimeters per day and the total annual evaporation is approximately 1,800 millimeters. Thus the average annual evaporation exceeds the average annual rainfall, implying water stress during certain periods of the year.

The area's topography is rolling and undulating with many outcropping rocks. Soils are relatively shallow, and groundwater is not extensively available in this hard rock region.

Given the seasonal and yearly variability of rainfall and the relative scarcity of groundwater, small tanks are very important for agriculture in the Anuradhapura District. There are 315 tank cascades wholly or partially within the district, which include over 4,000 small tanks. Centered on these small tanks, a whole pattern of agriculture and living has developed (Abeyratne 1956; Leach 1961; Brow 1978). Indeed, the village tank, along with the Buddhist temple and the village itself, has come to symbolize the ancient rural roots of Sri Lanka (Spencer 1990).

Assessment of Tank Cascade Hydrology

Alternative Methods

We define cascade water surplus as the quantity of water discharged annually at the base of the cascade after satisfying the present water demand for agriculture as a percentage of total water supply available to the cascade. Basically, it represents the difference between water supply available to the cascade and present water use adjusted for the scale of total water use.

In cascades, water-related activities initiated at one point will affect points lower down the system. If the cascade water surplus can be estimated accurately, water use planning within the cascade can be done without causing unnecessary conflicts. In a cascade with little water surplus, rehabilitation measures such as expansion of tank capacities or of command areas, diversion of water from one tank to another, or any combination of these measures will entail reduction of supply to tanks further down the cascade. In such cases, water use will only be shifted from one point in the cascade to another. On the other hand, if there is a significant cascade water surplus, there will be potential to increase water use at specific points within the cascade without affecting downstream users.

The initial task is to determine the overall water availability within the cascade by estimating the cascade water surplus. The primary problem is the estimation of actual outflow from the cascade. It can be done in three ways, in descending order of preference:

- actual measurement over a number of years
- collecting data from farmers, and observation using rapid assessment methods and calculation of outflow from a computer simulation model
- use of empirical relations between some simple measurements and outflow

If measurements of cascade outflow were available, this would have been the best way. But flow between tanks and from cascades in Sri Lanka's dry zone have seldom been measured. Also, little data exist on the physical and hydrologic characteristics of tanks and their interactions within the cascade. Since we did not have adequate flow measurements, we devised the two other approaches listed.

Estimating Cascade Outflow with a Simulation Model

Our preferred method for estimating cascade outflow involves four steps: (1) use maps to screen the cascades to select a group of cascades for further investigation; (2) use rapid assessment techniques to collect data on the initially selected cascades (the data can be used for further screening of cascades); (3) for the selected cascades, use participatory appraisal and planning techniques to further investigate and plan rehabilitation with farmers; (4) use the collected data and a computer simulation model to determine the expected outflow from each cascade.

To determine water availability in the cascade, the key information was data gathered from farmers on spilling from the tanks, including period, frequency, and approximate quantities. The advantage of this procedure is that the initial rehabilitation plans are discussed with farmers while determining the key data needed to evaluate cascade water surplus.

Initial Cascade Screening

The first step in cascade screening is to use topographic maps to identify the cascade and make key measurements. Then for each cascade, the total surface area, the total tank surface area boundaries, and the total command area are measured.

From the earlier studies of small tank and tank cascade hydrology, we developed two criteria for selecting cascades:

- the ratio of cascade area, A_c, to the total tank water surface area in the cascade, A_{cws}
- the ratio of cascade command area, A_{cca}, to the total tank water surface area in the cascade, A_{cws}

For a cascade to be chosen for further consideration, the former ratio should exceed 8 and the latter ratio should be less than 2. These are generalizations from criteria developed for individual tanks (IIMI 1994, Sakthivadivel et al. 1996) with the substitution of mean annual rainfall for mean maha season rainfall. Annex A gives the derivations of these criteria for tanks.

In the study for IFAD (IIMI 1996a), land use specialists on the IIMI team made measurements from standard 1:50,000 topographic maps of Anuradhapura District and then used the two criteria to select 76 out of 240 cascades.

Cascade Data Collection

The second step is to visit the cascades selected in the initial screening and use rapid assessment methods to collect information on water resources, agricultural land (currently cultivated, potential for expansion), cropping pattern, seasonal cropping intensities, population details (number of farmers under each tank), tank details (number of tanks in a village, spilling details, physical condition, year of last rehabilitation), tank management (responsibility for tank management), and groundwater use (numbers of wells, water quality).

In the IFAD study (IIMI 1996a), this information was collected by interviewing small groups of knowledgeable farmers in each village. A form was used to speed and focus data collection. At the same time or later, the field team visited and observed almost all tanks to confirm the interview data.

From the data, each cascade is scored to assess its land, water, and labor resources potential. Table 1 shows the scoring system we used. The individual items in this table correspond to key dimensions of evaluation:

- the greater the number of beneficiaries, the better use of investment funds
- the greater the landholdings, the more each beneficiary can benefit

TABLE 1.
Scoring for assessing land and water resources potential of a cascade.

Score	Criterion
	Potential beneficiary families
0	Less than 500 families
1	500 families or more
	Average family landholding
0	Less than 0.25 ha
1	0.25 to 1 ha
2	More than 1 ha
	Maha season cropping intensity
0	100%
1	99%–75%
2	74%–50%
3	Less than 50%
	Yields
0	Low due to soil, weather, or other conditions
1	Low due to low level of input application
2	Yield low due to insufficient water
	Frequency of tank spilling
0	Over 50% of tanks do not spill
1	Over 50% of tanks spill occasionally
2	Over 50% of tanks spill annually
	Duration of spills
0	Over 50% of tanks spill less than 7 days in a row per season
1	Over 50% of tanks spill 7–15 days per season
2	Over 50% of tanks spill for more than 15 days per season
	Spills at the bottom of the cascade
0	Last two tanks do not spill
1	Last two tanks spill
2	Over two tanks in the tail end of the cascade spill
	Physical condition
0	In over 50% of tanks, headworks are in good condition
1	In over 50% of tanks, some headworks components need repair
	Conjunctive water use
0	Over 50% of existing agrowells have insufficient water
0	Over 50% of existing agrowells have unsuitable water quality
1	Over 50% of existing agrowells have sufficient good quality water
	Potential new land for development
0	Less than 20 ha of additional land can be irrigated
1	20 to 100 ha of additional land can be irrigated
2	Over 100 ha of additional land can be irrigated
	Special factors
0	None
1	Moderately significant factors
2	Significant factors

Source: Adapted from IIMI 1996a.

- if yields are low due to insufficient water, the greater the potential yield gains from tank system improvements
- if the tanks spill, the greater the cascade water surplus of the cascade
- if the tank systems are in poor physical condition, the more they will benefit from rehabilitation
- having groundwater implies that better water supplies may help the groundwater or vice versa
- the greater the potential to irrigate new land, the greater the potential to benefit from investment

No one item in this scoring system is definitive; the scoring index must be considered as a whole. The higher the score, the better the cascade's potential for development.

These scores can be used to further reduce the number of cascades being considered. In the 1996 study for IFAD (IIMI 1996a), we used these data to narrow the selected cascades from 76 to 50, a number that had been predetermined based on the resources likely to be available for small tank rehabilitation.

Multilevel Participatory Planning

The third step is to conduct participatory planning sessions with farmers from all villages within each cascade. We call the technique used multilevel participatory planning because it involves getting farmers in each village to propose work needed on their tank systems and then getting representatives from all the villages together to analyze the cascade hydrology and agricultural systems as the basis for defining development plans for the cascade. Participatory mapping was the main technique used for data analysis and planning. For a detailed description of the technique see Jinapala, Brewer, and Sakthivadivel 1996.

Participatory planning was essential for two reasons. First, both the farmers and we needed better information on hydrology and agriculture than exists in official records. Farmers have the necessary knowledge from their experience with their own systems. However, farmers generally know the situations only for their own tanks, not for the cascades as wholes. By getting them together they could share data and build a comprehensive picture of water resources and water use within each cascade.

Second, we found that because most farmers did not think beyond their own tanks, they were not aware of possibilities of augmenting tank water supplies from other sources; nor were they aware that augmenting water supplies might affect downstream farmers. Multi-village participatory planning allowed them to consider the development of water resources in the cascade as a whole so as to make the best use of the potential water supply and to avoid conflicts that might arise from improvements made without considering effects on downstream users.

The output of each effort was a set of six maps showing:

- cascade land and water resources
- cascade agricultural systems and land use
- cascade social and management institutions, roads, and other infrastructure
- proposed improvements to the use of land and water resources
- proposed improvements to agriculture
- proposed changes in land and water management institutions

Estimating Runoffs

The fourth step is to use a computer simulation model to calculate two important parameters: the cascade outflow, i.e., the runoff volume discharging at the foot of the cascade per unit area (Re) and the effective maha (main) season runoff (Ro) to individual tanks. Ro is the sum of rainfall runoff, direct rainfall on the tank water surface, surplus water from the upstream tank, and irrigation drainage water from the immediate upstream command area minus the sum of tank evaporation and seepage and percolation losses.

The computer model used to simulate the cascade daily hydrologic behavior is the Reservoir Operation Simulation Extended System (ROSES). This model was specifically developed for IIMI 1996a, but other models can be used as well. ROSES uses the widely accepted node-link method for water resource simulation. The model integrates modules for individual tank level, cascade level, and subbasin level. At the first level, the model simulates the water balance on an individual small tank. At the next level, the model aggregates the hydrologic behavior of all the tanks in a cascade for a given set of supply and demand conditions. The model provides graphical and tabular outputs of the results of calculations of the temporal pattern of storage volume, spilling, and water levels for every tank in the cascade as well as runoff at any point along the natural stream or river system. The model also has the ability to integrate the behavior of all the cascades within an entire river basin or subbasin.

The input variables for the simulation and the sources we used were:

- mean annual rainfall (government records)
- cascade area (measured from maps)

- command areas of cascade tanks (measured from maps and checked by field visits and records)
- present main (maha) season cropping intensity (from field data collection)
- crop evapotranspiration values (from published data and use of CROPWAT program)
- drainage return flow coefficients (from Itakura 1994)
- catchment runoff-rainfall relationships (from Ponrajah 1982)
- water application, conveyance, and distribution efficiencies (average values used by the Irrigation Department)
- seepage and percolation losses (average values used by the Irrigation Department)

An additional item needed for this model is a representative depth-area-volume relationship for the small tanks. We used the formula:

$$S_t = 0.4 \times A_t \times d$$

where St is the storage capacity of the tank, At is the surface area at full supply level, and d is the depth from full supply level to the sill of the tank sluice (effective tank depth). This relationship is an empirical one first proposed by Arumugam (1957) and confirmed by a study of 14 representative tanks carried out as part of this exercise (IIMI 1994).

Key outputs from the model are the inflows, water releases, and expected spilling from each tank. During field data collection, we gathered partially quantified estimates for these variables, particularly for tank spilling. We used these data from farmers to check the model's output to ensure that no major mistakes were made.

For IIMI 1996a, we used the model to evaluate the cascade water surplus of the 50 cascades and to validate farmer proposals for augmenting water supply to particular tanks.

Estimating Cascade Outflow from Area Measurements

In our first study (IIMI 1994), we argued that potential water availability for a tank could be evaluated using two easily determined ratios. The ratio of tank catchment area, A_{tca}, to tank water spread area, A_{tws}, represents the hydrologic potential of the tank. If this ratio is greater than 7.5, then the tank usually has sufficient water to improve its cropping intensity (Annex A). The second ratio, tank command area, A_{tco}, to tank water spread area, A_{tws}, describes the adequacy of the tank storage capacity to serve the command. We showed (see Annex A) that, for tanks of average depth, this ratio should be less than 2 in order to serve the command well. We generalized these relations to the whole cascade to provide the criteria for initial screening of the cascades from map data, as discussed earlier.

After our 1996 study of 50 cascades and 699 tanks (IIMI 1996a), we analyzed the data to validate the idea that the simulated outflows from tanks and cascades were related to easily measurable parameters such as cascade area, tank catchment area, tank water surface area, and command area. The relationships we found are shown in figures 2 to 5.

The effective runoff for an individual tank, R_o, is related to its catchment area, A_{tca}, with the regression equation:

$$R_o = 0.2738A_{tca} - 1.4861 \ (r^2 = 0.73)$$

FIGURE 2.
Net runoff (R_o) versus tank catchment area (A_{tca}).

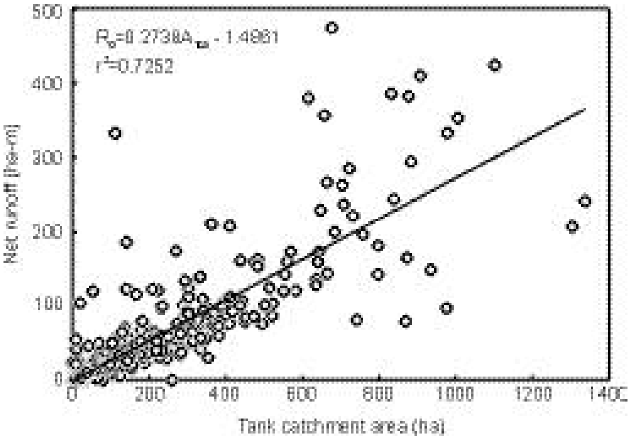


FIGURE 3.
Irrigation water demand (I_t) versus tank command area (A_{tco}).

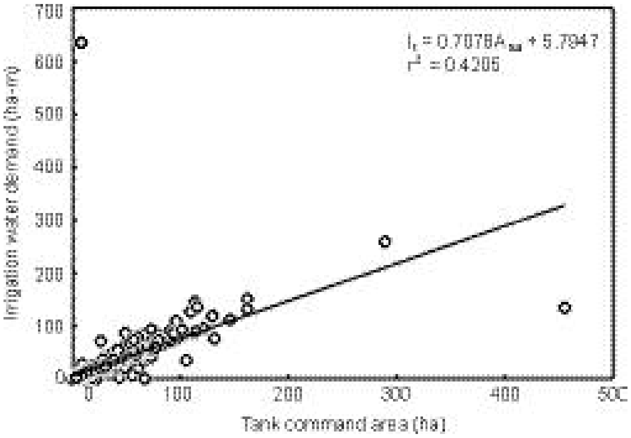
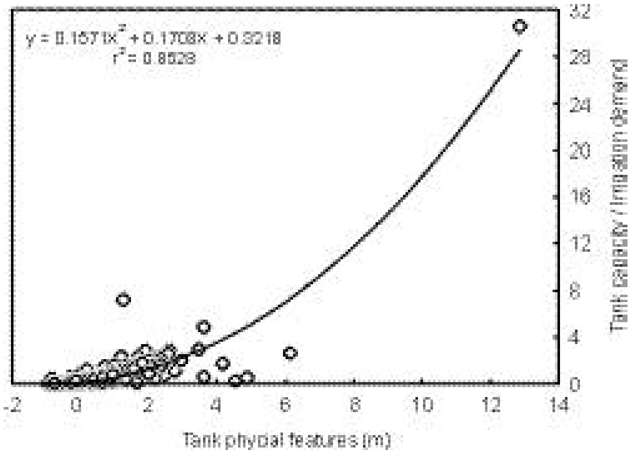


FIGURE 4.
Tank capacity/irrigation demand (S_t/I_t) versus tank physical features (X =1.22[A_{tws}/A_{tco}] + 0.62d – 1.52).



Tank system irrigation water demand, I_t, is related to the tank command area, Atco, by the regression equation:

$$I_t = 5.7947 + 0.7078A_{tco}\ (r^2 = 0.42)$$

The ratio of tank storage capacity, S_t, to tank irrigation water demand, I_t, is related to effective tank depth, d, and the ratio of tank water surface area, A_{tws}, to tank command area, A_{tco}, with the regression equation:

$$S_t/I_t = 0.1571x2 + 0.1703x + 0.3218,$$

where

$$x = 1.22(A_{tws}/A_{tco}) + 0.62d - 1.52\ (r^2 = 0.85).$$

The cascade outflow, R_c, is related to the cascade area, A_c, total tank water surface area in the cascade, A_{cws}, and the total command area in the cascade, A_{cca}, with the regression equation:

$$\log R_c = 1.4582 + 0.0003(A_c - A_{cws} - A_{cca})\ (r^2 = 0.44)$$

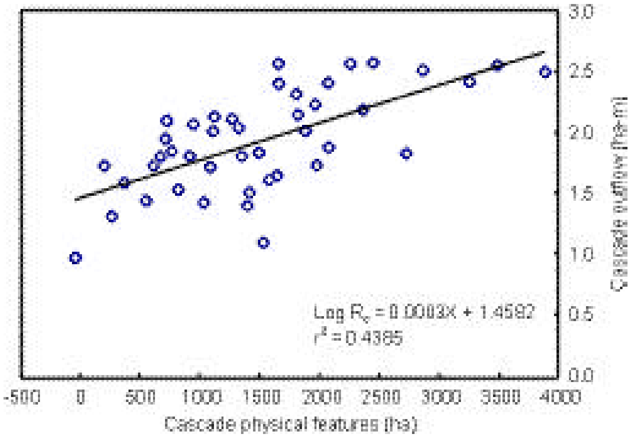
This analysis indicates that the cascade outflow is directly related to cascade area, command area, and tank water surface area of the cascade and indirectly to tank storage capacities and irrigation water demand. This analysis gives a quantitative expression to the fact that features of individual tank systems affect the cascade outflow. Incidentally, this analysis validates our use of the simple area ratios for initial screening of the cascades.

The last relation gives a direct way to estimate the cascade outflow from simple area measurements for the cascade.

Evaluating Cascade Water Surplus

To make use of the cascade outflow for rehabilitation planning, it is necessary to determine its significance. Specifically, in an average or above-average rainfall year, there

FIGURE 5.
Cascade outflow (log R_c) versus cascade physical features ($X = A_c - A_{cws} - A_{cca}$).



should be some volume of cascade outflow. Outflow is required to protect the environment; this requirement is related to the area of the cascade and the rainfall received by the cascade.

Outflow in specific quantities may also be required by users downstream. Thus, when evaluating outflow, the concern is whether the outflow is high enough for some portion of it to be productively distributed among some or all of the tanks in the cascade.

To evaluate the cascade water surplus, we first define cascade outflow per unit area, R_e, as the cascade outflow, R_c, divided by the cascade's total area, A_c:

$$R_e = R_c/A_c$$

Then we define the cascade water surplus, WS_c, as the ratio of the outflow per unit area, R_e, to the mean annual rainfall, R_{50}:

$$WS_c = R_e/R_{50}$$

For Anuradhapura District, we estimated that if this ratio is greater than 5 percent ($WS_c > 0.05$), the cascade has surplus water. We arrived at the 5 percent value from the following reasoning. First, the annual rainfall averages 1,500 millimeters in the district but varies from 1,200 millimeters to about 1,600 millimeters from place to place. Second, the total crop water requirement for rice in this area is about 650 millimeters, and about 450 millimeters normally seep into the groundwater. Subtracting these two values from the minimum annual rainfall (1,200 mm) leaves 100 millimeters. This would be the expected runoff in a fully developed cascade in the minimum rainfall situation. Third, 5 percent of the rainfall would be 60 to 80 millimeters, which is close to the 100 millimeter value mentioned above.

Five percent is an approximate value that should be refined from field measurements.

In our 1996 study, we did not consider uses of water downstream from the cascade itself. In Anuradhapura District and other parts of Sri Lanka, the bottom of the tank cascade is defined by the last tank system before water flows into a major river. The water in the major rivers is also used, notably for large-scale irrigation systems. It would also be good to take the requirements of these irrigation systems into account.

Basically then, for any cascade where the cascade water surplus is above the criterion—here 5 percent—the planning options to consider for tank system rehabilitation are expanding tank capacity or the command area or augmentation from additional sources. In any cascade where the water surplus is less than the criterion, no tank expansion or augmentation can be considered.

Assessment of Tank Rehabilitation Proposals

Planning Small Tank Rehabilitation

When planning small tank rehabilitation, there are three basic considerations. First, the types of investment that can be permitted must be specified. Second, since development funds are limited, the tank must be selected for investment based on relevant criteria. Third, for any selected candidate, the particular works to be carried out must be identified.

Earlier we suggested a procedure for determining the cascade water surplus including holding participatory planning sessions with farmers. One output of this process is a set of proposals for rehabilitation works, including proposals for both individual tank systems and augmenting tank systems. Planning then consists largely of deciding which proposals should be accepted.

The alternative, and more common, planning process involves experts visiting each candidate tank system and working out the rehabilitation proposals themselves, sometimes in consultation with farmers. When there is little detailed knowledge of the tank cascades, the participatory planning approach has several major advantages over planning by experts (Jinapala, Brewer, and Sakthivadivel 1996). One is that having the farmers make their own plans gives them ownership of the plans and makes their cooperation more likely and more effective. Since small tank rehabilitation projects generally require farmer input in the form of labor or cash, such cooperation is essential.

Another advantage relates to the effects tank augmentation or capacity expansion can have on the tank systems downstream in the cascade. When the farmers of the cascade are involved in planning, they can anticipate these effects based on their combined knowledge of cascade hydrology. Often, preliminary solutions to potential conflicts arise through negotiations among the farmers from different villages. These negotiations were quite common in our participatory planning sessions.

Also, as part of participatory planning, farmers can be asked to prioritize the proposed interventions. If resources are not sufficient for all of the proposed investments, selecting investments using the farmers' priorities is likely to be more politically acceptable than using other criteria. We found farmers were quite capable of applying their detailed local knowledge to prioritize the proposed interventions.

Finally, since participation of the farmers is essential to gather the data needed for each cascade, involving farmers in participatory planning is very efficient.

Various options can be considered when planning small tank rehabilitation:

- Repairs to the tank bund, sluice, and spill, to the main, secondary, and tertiary canals and their control structures, and to drains.
- Management improvements such as upgrading of information sources and management skills of the farmers who manage the system. These improvements may include installing measurement devices, training managers, creating management organizations, devising new rules, etc. They also include training farmers in more efficient application of water to crops and in other means of improving water use efficiency.

- Tank augmentation such as works intended to increase the water supply to the tank—a diversion canal from a stream not intercepted by the tank or a canal to take water from the spill of an upstream tank whose water would not normally flow to the tank under rehabilitation.

- Tank capacity expansion such as raising and lengthening the tank bund. Tank desiltation would fall into this category, but in Sri Lanka it has long been against government policy to fund tank desiltation even though farmers often request it.

- Command area expansion, where possible, to take advantage of excess water.

At the level we are considering here, the primary question is which categories of works should be considered. More planning is needed to define all of the details of a category of investment for any one tank system.

Hydrologic Evaluation of Individual Tanks

To identify the potential of the tanks in a cascade to benefit from repair and improvement, each tank must be evaluated using water resource availability, tank storage capacity, and agricultural criteria. Then to arrive at a set of repair and improvement recommendations, the farmers' proposals for the cascade and individual tanks are compared with the potential benefits.

Indicators for Evaluating Individual Tanks

Several indicators are used to evaluate the potential of a tank system to benefit from rehabilitation investment.

Tank Water Supply Adequacy. A cascade may be hydrologically well endowed, but a tank within it may not be so. Water supply adequacy of a tank measures the extent to which the effective runoff, R_o, to the tank is adequate to meet the irrigation requirement, I_t, in the main (maha) season. Water supply adequacy is evaluated using the ratio of these two values. If $R_o/I_t > 1$, the tank has adequate water supply to meet the irrigation requirement; otherwise, additional water is needed to meet this requirement.

Tank Storage Capacity. The storage capacity, S_t, of a tank measures the extent to which the tank is capable of storing the runoff water and releasing it to meet the irrigation requirement, I_t. This measure is evaluated using the ratio of these two quantities. If $S_t/I_t > 0.3$ then the tank has the capacity to hold at least 30 percent of the irrigation requirement. The value of 0.3 is arrived at based on the farmers' perception that a tank should have the capacity to hold at least 5 weeks of irrigation requirement before starting any irrigation operation.

Cropping Intensity. Agricultural performance of a tank is a measure of the extent to which the command area of a tank is cultivated with irrigation water successfully in maha seasons. It is evaluated using the average main season (maha) cropping intensity, CI_m, for the past few consecutive seasons. In our 1996 study (IIMI 1996a), information on average maha cropping intensity for the last few maha seasons for each tank was collected from the farmers. Based on the variability of rainfall and findings in our 1996 study, we concluded that a well-performing cascade or tank in Anuradhapura District would have a maha season cropping intensity of 60 percent or more.

These indicators, together with the cascade water surplus indicator are used to define the rehabilitation components recommended.

Recommending Tank Rehabilitation Components

The indicators lead to the following recommendations:

- Tank repairs in all hydrologic situations.
- Management improvements if the main season cropping intensity for the tank is low ($CI_m < 60\%$).
- Tank augmentation if there is a cascade water surplus ($WS_c > 5\%$) and tank water supply is inadequate ($R_o/I_t < 1.0$).
- Tank capacity expansion if there is a cascade water surplus ($WS_c > 5\%$), the tank water supply is adequate ($R_o/I_t > 1.0$), but the tank storage capacity is inadequate ($S_t/I_t < 0.3$).
- Both tank augmentation and tank capacity expansion if there is a cascade water surplus ($WS_c > 5\%$), tank water supply is inadequate ($R_o/I_t < 1.0$), and tank storage capacity is inadequate ($S_t/I_t < 0.3$). In this case, the tank capacity must be expanded to make use of the increased water supply to be provided through tank augmentation. However, if there is no source of water for tank augmentation, then tank expansion is not needed.
- Command area expansion, only when a cascade water surplus exists ($WS_c > 5\%$), tank water supply is adequate ($R_o/I_t > 1.0$), tank storage capacity is adequate ($S_t/I_t > 0.3$), cropping intensity is high ($CI_m > 60\%$), and land for command area expansion is easily available.

The purely hydrologic indicators bear only on recommendations for tank system augmentation or expansion. Table 2 gives the conditions that support the recommendations. Recommendations for tank repairs are independent of the hydrologic evaluation and have to be based on other criteria such as cost-benefit estimates. Similarly, recommendations for management improvements are based solely on cropping intensity, which is used as a measure of system agricultural performance.

These criteria alone do not provide a full basis for deciding whether and how to invest in any particular tank system. Additional, nonhydrologic, criteria are needed.

TABLE 2.
Recommendations on tank system augmentation and expansion.

Tank system conditions				
Cascade surplus	Tank water availability	Tank storage capacity	Cropping intensity	Recommendations
no	–	–	–	No expansion/augmentation
yes	not adequate	–	–	Tank augmentation
yes	adequate	not adequate	–	Tank capacity expansion
yes	not adequate	not adequate	–	Augmentation and capacity expansion[a]
yes	adequate	adequate	high	Command area expansion[b]

[a] Capacity expansion is recommended only if tank augmentation will actually be carried out.

[b] Only if appropriate land is available.

Confirming the Data

The set of data on which these hydrologic evaluations are based comes from farmers' recollections that are not well quantified rather than from detailed measurements. For this reason, wherever the data and the rules recommend proposals for tank augmentation, tank expansion, or command area expansion, it is critical that the basic data be checked. In our experience, farmers not only accept the necessity for such checking but welcome it.

Evaluating Tank Rehabilitation Proposals against Nonhydrologic Criteria

While the hydrologic evaluation provides guidelines on the kinds of rehabilitation to propose to avoid conflicts over water, it does not provide sufficient guidance to pinpoint which tank systems to rehabilitate and how much to invested in each. Additional criteria are required. For a government-sponsored rehabilitation project, these will necessarily be politically acceptable social and economic criteria.

It is not our intention to recommend any particular criterion. To illustrate criteria that might be used, we will describe those adopted in Anuradhapura District under the project that IIMI assisted.

Criteria for Selecting Tank Systems for Rehabilitation

In Anuradhapura District, the various project authorities use two key criteria to eliminate small tank systems from consideration: the number of beneficiaries and the rehabilitation history.

The number of beneficiaries refers to how many farm families would benefit from repairs and improvement. For the Anuradhapura District project, it was decided that there must be at least five beneficiaries for a tank system to be considered for rehabilitation. The rehabilitation history pertains because small tank rehabilitation has been popular, and many systems have already had some form of rehabilitation. Authorities in the Anuradhapura District project decided that a tank system would be reconsidered for rehabilitation only if the last rehabilitation had occurred at least 10 years earlier.

These two criteria eliminate many tanks from consideration for rehabilitation. Further elimination may have to be made using other criteria, particularly those that allow explicit or implicit comparison of costs and benefits of each investment.[1]

Evaluating Investment in Tank System Repairs

Under the criteria given so far, tank system repairs are recommended for all tanks selected for rehabilitation. Because funds are limited, a means of estimating the level of investment in tank repairs is useful for planning.

For this purpose, we developed the tank system physical status score (PSS) to give an idea of the level of investment needed for each tank system. The PSS system is shown in table 3. In this scoring system, the more important items (tank bunds, tank sluices, tank spills, and the canal systems) have been given double the weight of the other items. The higher the score, the more the repairs needed; a tank system in the worst possible condition would receive a score of 100.

For simple estimation, we proposed that if the computed PSS is greater than 60, then the tank needs heavy capital investment; if it is between 40 and 60, then

[1] For example, one author (Fernando) strongly argues that priority should be given to repairing tanks that do not function because they are breached. This is based on the idea that making a tank function is likely to be more valuable to the beneficiaries than improving the performance of an already functioning tank. Of course, this must be considered a form of tank capacity expansion when evaluating such proposals.

TABLE 3.
Physical status scoring for individual tanks

Tank bund	
20	Breached
16	Badly dilapidated
12	Moderately dilapidated
8	Fairly good
4	Good
0	No problems
Tank bed	
10	Heavily silted
6	Moderately silted
0	Unsilted
Tank sluice(s)	
20	Not working and need(s) replacement
12	Dilapidated and need(s) major repair
4	Good/minor repairs
0	No problems
Tank spill	
20	Nonexistent
12	Needs replacement/needs major repairs
4	Good/minor repairs
0	No problems
Canal system	
20	Heavily dilapidated
12	Moderately dilapidated
4	Minor repairs
0	No problems
Inflow streams	
10	Heavily clogged
6	Moderately clogged
2	Not much clogging
0	No clogging

the tank needs moderate investment and if it is less than 40, then the tank needs only low investment. Per hectare cash costs can then be assigned to these classes for preliminary budgeting. The costs then form another basis for selecting tank systems for rehabilitation.

Makichchawa Cascade: An Example of Applying the Methodology

In this section, we analyze the Makichchawa cascade to illustrate and explain the use of the methodology. The Makichchawa cascade (fig. 6) is one of 50 in the Anuradhapura District studies in 1996 (IIMI 1996a). Proposals and recommendations for the tanks in the cascade are summarized in table 4. An explanation for these recommendations is given below.

Evaluation of Cascade Water Surplus

As shown in Annex B, the cascade water surplus (WS_c) for the Makichchawa cascade is 8.1 percent, well above the standard of 5 percent required for a cascade to be classed as having a significant water surplus. Therefore, tank augmentation, tank capacity expansion, and command area expansion can be considered, including restoration of breached tanks.

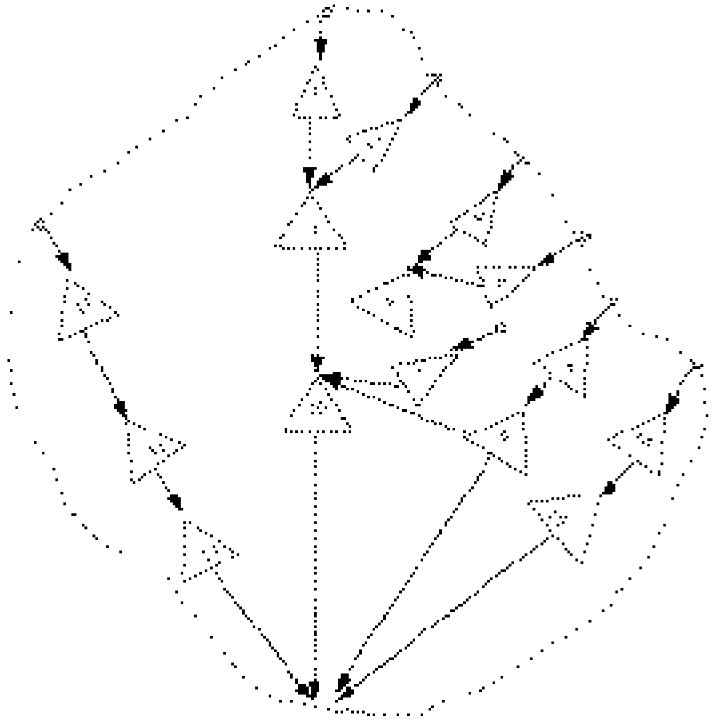
Eligibility for Tank Rehabilitation and Repair

All tanks in the Makichchawa cascade, except tank 7, have at least five farmers (table 4). Hence all except tank 7 are eligible on the grounds of sufficient beneficiaries (tank 7 is a special case and is discussed separately, below). However, tank 3 (Etambagaskada tank), tank 10 (Makichchawa tank), and tank 14 (Kuda Kongollewa tank) have been rehabilitated within the last 10 years (table 4). Tank 10 was undergoing rehabilitation at the time of fieldwork. These three tanks are, therefore, not eligible for rehabilitation.

Evaluation of Rehabilitation Proposals

Table 4 shows the farmers' proposals, the hydrologic evaluation indicators, the maha season cropping intensity, CI_m, and the PSS for each tank. The hydrologic evaluation indicators are R_o/I_t (ratio of runoff to tank irrigation requirement) and S_t/I_t (ratio of tank storage capacity to tank irrigation requirement).

FIGURE 6.
Schematic relationship of the tanks in the Makichchawa cascade.



1. Thimbiri
2. Dutu
3. Etambagaskada
4. Maha Meegaskada
5. Kuda Meegaskada
6. Maha Divulgaskada
7. Kuda Divulgaskada
8. Palugolla
9. Puhudivula
10. Makichchawa
11. Nuga
12. Vedikkarayage
13. Kadawatha
14. Kuda Kongollewa
15. Ratmalwetiya

To see how these are used, let us take the example of tank 4 (Maha Meegaskada tank). The R_o/I_t ratio for tank 4 is only 0.54. Augmentation from another source should be considered to raise the ratio to at least 1, which is adequate. Farmers proposed augmentation by diverting a stream called Ulpath Ela to the tank. This proposal is thus recommended.

Tank 4 also has less than adequate capacity since the S_t/I_t ratio is 0.26. The S_t/I_t ratio should be at least 0.3. The farmers proposed extending the bund of tank 4 to reach the end of the bund of nearby tank 5, combining the two tanks and effectively increasing the capacity of both tanks. This proposal is also thus recommended.

The maha cropping intensity for tank 4 is 0.76. Because maha cropping intensity over 0.6 is considered high, management improvements are not recommended.

Tank repairs are recommended for all eligible tanks. Therefore, the tank 4 farmers' proposals to repair the bund and provide a spill on the right bank are also recommended. Since the PSS is 82, tank repairs will require a high level of investment.

Tank 9 (Puhudivula tank) offers a contrasting example. The R_o/I_t ratio for tank 9 is 0.99, close enough to 1.0 that augmentation is not needed for this tank, nor did farmers propose it.

The S_t/I_t ratio for tank 9 is 0.65, well above 0.3. This tank therefore has adequate capacity and capacity expansion is not warranted. The farmers, however, proposed raising the tank bund to increase the capacity. This proposal is not recommended.

The maha cropping intensity is 1.0, and therefore there is no need for management improvements.

TABLE 4.
Evaluation of tank rehabilitation proposals for Makichchawa cascade.

	Evaluation indicators								
	Farmers (no.)	Rehab. year	R_o/I_t	S_t/I_t	CI_m	PSS	Farmer proposals in priority order	Recommendations	Invest level
1.	Thimbiri (breached tank)								
	20	–	4.98	0.43[a]	–	70	Restore tank bund	Capacity restoration by bund repair	High
							Provide spill	Tank repairs	
							Provide channel system		
2.	Dutu (breached tank)								
	8	–	6.45	0.60[a]	–	66	Restore tank bund	Capacity restoration by bund repair	High
							Provide spill and sluice	Tank repairs	
3.	Etambagaskada								
	105	1992	6.19	0.96	0.75	66	Repair bund	Not eligible	–
							Repair leaks in sluices		
							Repair canal system		
4.	Maha Meegaskada								
	65	–	0.54	0.26	0.76	82	Divert local stream into tank	Tank augmentation	
							Repair bund; fill scours and depressions	Tank repairs	
							Provide a spill on the right bank	Combine tanks (capacity increase)	High
							Connect to Kuda Meegaskada by extending bund		
5.	Kuda Meegaskada								
	65	–	3.05	0.39	0.77	72	Repair bund; fill breach, scours, and depressions	Tank repairs	High
							Replace step sluice with control gated sluice	Plan work with plans for Maha Meegaskada	
							Provide sluice	Consider command area increase	
							Provide channel system		
6.	Maha Divulgaskada								
	65	1976	1.53	0.44	0.67	46	Repair left bank sluice leaks and bent spindle	Tank repairs	Med.
							Repair right bank sluice leaks	Consider command area increase	
							Repair spill damage and leaks; provide gates and locks		
							Provide channel system		
7.	Kuda Divulgaskada (not used for irrigation)[b]								
	–	–	–	–	–	52	Construct canal to Maha Divulgaskada	See text	See text
8.	Palugolla (severe leaks in bund)								
	35	1976	0.76	0.18[a]	–	62	Divert drainage from local hill into tank	Capacity restoration by bund repair	High
							Repair bund leaks; fill scours and depressions	Tank augmentation	
							Replace LB step sluice	Tank repairs	
							Provide channel system	Consider capacity increase	

(Continued).

TABLE 4. *(Continued)*

Evaluation indicators								
Farmers (no.)	Rehab. year	R_o/I_t	S_t/I_t	CI_m	PSS	Farmer proposals in priority order	Recommendations	Invest level
9. Puhudivula								
45	1978	0.99	0.65	1.0	66	Raise bund; fill scours and depressions Repair sluice gate leak Provide spill Provide channel system	Tank repairs	High
10. Makichchawa (currently under rehabilitation)								
89	1996	23.21	2.41	0.81	24	None	Not eligible	–
11. Nuga (breached tank)								
15	–	0.59	0.14[a]	[c]	64	Restore tank bund Provide spill Replace step sluice with gated sluice	Capacity restoration by bund repair Tank repairs Consider capacity increase	High
12. Vedikkarayage (breached tank)								
12	1965	1.03	0.27[a]	[c]	46	Restore tank bund Provide sluice Provide spill	Capacity restoration by bund repair Tank repairs Consider capacity increase	Medium
13. Kadawatha								
8	1965	1.73	0.46	1.0	86	Repair bund; fill breaches, depressions, and scours Replace step sluice with control gated sluice	Tank repairs Consider command area increase	High
14. Kuda Kongollewa								
5	1995	0.74	0.32	0.33	54	Provide spill	Not eligible	–
15. Ratmalwetiya								
15	–	1.78	0.21	0.58	82	Repair bund; fill breaches, depressions, and scours Replace step sluice with control gated sluice	Tank repairs Management improvements Consider capacity increase	High

[a] Tank has no effective capacity; the value represent what the capacity would be if it functioned.

[b] See discussion of this tank in the text.

[c] Farmers use the command area for rain-fed cultivation during maha.

Tank repairs are recommended. For tank 9, farmers proposed repairing the bund and the sluice gate, and providing a spill and a channel system. The PSS of 66 indicates that the required investment level for these repairs is high.

Four of the tanks in the cascade (tanks 1, 2, 11, and 12) are breached so that they will not hold water. Another (tank 8) will not hold water due to severe leaks in the bund. Because this is a surplus water cascade, restoration of all of these tanks can be recommended. However, before going ahead, it is essential to determine whether the cascade water surplus is sufficient for all of them.

For tanks 8, 11, and 12, the storage capacity will not be adequate even after their capacity has been restored. Therefore, we recommend consideration of capacity increases, in addition, for these tanks. Tank 8 also does not receive adequate water, hence augmentation of water supply, as proposed by the farmers, is recommended.

If a tank has adequate water and adequate storage capacity and has a high cropping intensity, the procedure recommends consideration of command area enlargement if suitable land is available. This is the case for three of the tanks (tanks 5, 6, and 13).

Tank 7 (Kuda Divulgaskada tank) is unusual. At present, this tank is not used for irrigation. In the dry zone of Sri Lanka, almost all agricultural land is owned by the government. Legally, it can be farmed only with a government permit. No permits have been issued for land under tank 7; hence this tank is not legally used for irrigation.

Farmers under nearby tank 6 (Maha Divulgaskada tank) proposed using the water stored in tank 7 by building a canal to convey that water to tank 6. Tank 6, however, has adequate water by the standards used here ($R_o/I_t = 1.53$). Therefore, we do not recommend construction of this canal. However, tank 6 is one of the tanks eligible for command area increase. It is possible, therefore, that further investigation would show that farmers could use the water by enlarging the command under tank 6.

Need for Further Checks

The procedure described permits a systematic and rational approach for selecting tank rehabilitation activities. The procedure takes into account cascade water limitations, individual tank characteristics, social and economic criteria, and farmers' requests. This is a far more systematic approach than has been used before in planning small tank rehabilitation in Sri Lanka.

However, it is essential that further assessments of the tank and cascade hydrology be made to determine the effects of the recommended activities. This should be done before construction begins.

Extension of the Methodology

This report has described a methodology for planning the rehabilitation of small-scale irrigation systems in the dry zone in Sri Lanka. This methodology has been designed to ensure that rehabilitation of a scheme will be fruitful by ensuring that water is available to allow for increased cropping intensity. It also attempts to ensure that the rehabilitation of any one small-scale system does not cause problems for other water users in the basin.

The main advantage of the methodology described here is that it provides a means of rapid assessment of water availability and water use without requiring the existence or the creation of a detailed hydrologic database for the basin. Instead, farmers' knowledge of their hydrologic situations is harnessed to provide the needed data. That knowledge and data gained from well-designed rapid assessments are used to estimate flows among the separate systems within the basin and outflows from the basins.

The methodology as described is adapted to the specific needs of small tank systems in small basins in Sri Lanka's dry zone. However, this methodology can be used elsewhere.

Small Tank Cascades

Tank cascades have been in existence in the semiarid dry tracts of South Asia for centuries. They are one of the earliest sources of water supplies for agricultural production and human use in Sri Lanka, India, and Nepal. In India, tank cascades are characteristic of Tamil Nadu, Karnataka, Andhra Pradesh, and parts of Maharashtra (von Oppen and Subba Rao 1980). Tamil Nadu alone has almost 40,000 small tank systems and Andhra Pradesh has over 70,000 (Maloney and Raju 1994).

The methodology proposed here can be used with minimal modifications for planning irrigation system rehabilitation in these situations since they are environmentally and technologically similar to the situation in Sri Lanka's dry zone.

Other Small-Scale Irrigation Systems

With some modifications, this methodology can be used for irrigation system rehabilitation in any small water basin where uses are dominated by small-scale irrigation systems. These include, for example, the farmer-built systems in the river valleys of Bali (Lansing 1991) and the 15,000 farmer-managed systems in the hill areas of Nepal (Pradhan 1989).

The irrigation systems in such situations are often not tank systems—in both Bali and Nepal, the small-scale systems are diversion systems. The basic principle that basin water surplus is to be used to judge whether individual systems can be expanded remains the same. However, because the means of expanding the systems are different from cascade systems, the means of calculating what expansion is allowable necessarily differs.

Larger Basins and Larger Irrigation Systems

The methodology itself cannot be used directly to deal with rehabilitation planning of larger systems or in larger basins, primarily because of the logistical problem that getting information from a significantly larger number of farmers presents. Also in larger basins or larger systems, water uses other than for irrigation are likely to be important.

Certain principles underlying the present methodology, however, can be used for planning water resource development in these situations. One is that expansion of irrigation systems within a basin that does not have a water surplus should not be permitted. This ban on expansion may, however, have to be modified for consideration of transfer of water from irrigation to other uses.

Another principle is that although large-scale irrigation systems are likely to have hydrologic data available, there are often small-scale systems within the basin that do not. The participatory methods of collecting the data described here can provide such information. Similarly, the approach to estimating water resources based on rainfall and areas can be used in these circumstances.

Finally, the key principle underlying this approach is that development of any use of water within a basin must be viewed in the context of the whole basin to avoid conflicts over water use. The techniques and principles used in our methodology may be useful for water resource development planning in other circumstances to avoid conflicts over water.

ANNEX A

Derivation of Limiting Values for Tank Hydrologic Indicators

The following basic assumptions are made in deriving limiting values for the tank indicators:

1. Maha rainfall contribution to runoff should be equal to or greater than 1.5 times the maha irrigation water requirements.
2. A maximum of 1.5 tank fillings is required for the maha crop to mature.
3. The rainfall runoff coefficient is 0.3.
4. The mean maha rainfall, which varies between 600 and 900 millimeters in the North Central Province, will be used for runoff computations.
5. The irrigation water requirement at the tank outlet is taken as 0.9 ha-m/ha.
6. Tank storage capacity, S_t, is computed using the equation $S_t = 0.4 \times A_{tws} \times d$, where Atws is the tank water spread area and d is the effective tank depth at sluice head (depth from full supply level to the sill level).

Based on these assumptions, the following limiting values can be derived:

Ratio of tank catchment area to the tank command area

Assumption 1 implies that

$$\frac{\text{tank runoff volume}}{\text{tank irrigation water requirement}} > 1.5$$

From assumptions 3 and 4, tank runoff volume is $A_{tca} \times 0.3 \times R_{50}$, where A_{tca} is the tank catchment area and R_{m50} is the mean (50% probable) maha rainfall. Also, from assumption 5, the tank irrigation water requirement is $A_{tco} \times 0.9$ meters, where A_{tco} is the command area. When substituted in the above equation, the result is

$$(A_{tca} \times 0.3 \times R_{m50})/(A_{tco} \times 0.9) > 1.5$$

or, simplifying,

$$A_{tca}/A_{tco} > 4.5/R_{m50} \qquad (1)$$

The limiting values depend upon the expected maha rainfall: $A_{tca}/A_{tco} > 5$, when $R_{m50} = 0.9$ meters and $A_{tca}/A_{tco} > 7.5$, when $R_{m50} = 0.6$ meters.

Ratio of tank command area to the tank water spread area

From assumption 2, we have that

$$\frac{\text{tank irrigation water requirement}}{\text{tank storage capacity}} > 1.5$$

From assumption 5, the tank irrigation water requirement is A_{tco} x 0.9 meters. From assumption 6, the tank storage capacity is A_{tws} x 0.4 x d, where A_{tws} is the tank water spread area (in hectares) and d is the effective depth of the tank at the sluice (in meters). When substituted in the above equation the result is

$$(A_{tco} \times 0.9)/(A_{tws} \times 0.4 \times d) < 1.5$$

or, simplifying,

$$A_{tco}/A_{tws} < 2d/3 \qquad (2)$$

which can be interpreted as $A_{tco}/A_{tws} < 1$, where $d < 1.5$ meters; $A_{tco}/A_{tws} < 2$, where $d = 1.5$ to 3.0 meters; and $A_{tco}/A_{tws} > 2$, where $d > 3.0$ meters.

Ratio of tank catchment area to the tank water spread area

First, note that

$$A_{tca}/A_{tws} = (A_{tca}/A_{tco}) \times (A_{tco}/A_{tws})$$

Substituting from equations (1) and (2) gives:

$$A_{tca}/A_{tws} \geq (4.5/R_{m50}) \times (2d/3)$$

or, simplifying,

$$A_{tca}/A_{tws} \geq 3d/R_{m50}$$

Then consider three cases:

(a) When $d < 1.5$ meters and the mean maha rainfall varies between 900 and 600 millimeters, then $A_{tca}/A_{tws} < 7.5$

(b) When d varies between 1.5 and 3.0 meters and the mean maha rainfall varies between 900 and 600 millimeters, then $7.5 < A_{tca}/A_{tws} < 10$

(c) When $d > 3.0$ meters and the mean maha rainfall varies between 900 and 600 millimeters, then $A_{tca}/A_{tws} < 10$

ANNEX B

Makichchawa Cascade Data

Location

Cascade name: Makichchawa
River basin: Malwatu Oya
Divisional Secretary Division: Medawachchiya

General Information

Cascade area: 2,816.2 ha
Number of tanks: 15
  Working: 9
  Nonworking: 6
Agricultural wells: 11

Cascade Hydrologic Characteristics

Total cascade area (A_C): 2,816.2 ha
Total cascade water spread area (A_{CWS}): 170.4 ha
Total cascade command area (A_{CCA}): 294.6 ha
Mean tank depth (d): 1.93 m
Mean annual rainfall (R_{50}): 1.587 m (Mahailluppallama station)
Cascade maha cropping intensity (CI_C): 0.79
Net annual runoff from the cascade (R_C): 363.0 ha-m

Computation of Screening Indicators

Ratio of cascade area to cascade water spread area:
$A_c/A_{cws} = 2816.2/170.4 = 16.5 > 8$
Ratio of cascade command area to cascade water spread area:
$A_{CCA}/A_{CWS} = 294.6/170.4 = 1.7 < 2$
The cascade satisfies the two criteria for selection in the preliminary screening round.

Computation of Cascade Water Surplus

Cascade outflow per unit area: $R_e = R_c/A_c = 363.0/2816.2 = 0.1289$
Cascade water surplus: $WS_c = R_e/R_{50} = 0.1289/1.587 = 0.0812$
$= 8.1\% > 5\%$

Since the water surplus exceeds 5 percent, Makichchawa is considered a water-surplus cascade.

Basic tank features.

Tank		Area (ha) Command	Catchment	Water spread	Depth (m)
1.	Thimbiri	12.1	328.6	8.5	1.8
2.	Dutu	9.7	235.1	11.3	1.0
3.	Etambagaskada	48.6	498.2	37.6	2.4
4.	Maha Meegaskada	34.4	62.7	8.1	2.1
5.	Kuda Meegaskada	18.2	204.8	6.5	2.1
6.	Maha Divulgaskada	72.8	178.5	22.7	2.7
7.	Kuda Divulgaskada	–	119.8	1.8	1.5
8.	Palugolla	12.1	31.9	2.4	1.8
9.	Puhudivula	26.7	75.3	15.8	2.1
10.	Makichchawa	22.3	534.2	43.3	2.4
11.	Nuga	8.1	16.2	1.8	1.2
12.	Vedikkarayage	8.1	19.0	2.0	2.1
13.	Kadawatha	4.9	38.8	3.4	2.1
14.	Kuda Kongollewa	6.1	19.4	2.8	1.8
15.	Ratmalwetiya	10.5	38.4	2.4	1.8

Tank water balances for maha seasons (ha-m).

Tank	Begin storage	Inflows Catch-ment	Direct rainfall	Drainage	Tank spills	Outflows Spillage	Irrig-ation	Losses	End storage
1. Thimbiri	0	78.26	9.33	0.00	0.00	55.21	14.19	16.83	1.37
2. Dutu	0	56.00	12.35	0.00	0.00	38.18	7.51	19.91	2.75
3. Etambagaskada	0	174.26	38.71	4.34	93.39	172.13	37.53	78.44	22.60
4. Maha Meegaskada	0	14.94	1.89	0.00	0.00	0.00	13.99	2.43	0.40
5. Kuda Meegaskada	0	48.78	6.75	0.00	0.00	25.53	14.07	12.66	3.28
6. Maha Divulgaskada	0	69.37	17.14	5.61	25.53	25.77	55.46	31.70	4.74
7. Kuda Divulgaskada	0	28.52	2.07	0.00	0.00	25.66	0.00	3.87	1.08
8. Palugolla	0	7.61	1.29	0.00	0.00	0.52	6.43	1.73	0.21
9. Puhudivula	0	22.06	6.66	1.29	0.52	0.00	19.81	10.15	0.57
10. Makichchawa	0	209.05	46.33	18.60	223.55	349.94	17.21	97.95	32.46
11. Nuga	0	3.85	0.77	0.00	0.00	0.10	3.52	0.91	0.09
12. Vedikkarayage	0	6.24	1.25	0.70	0.10	0.77	5.48	1.87	0.18
13. Kadawatha	0	11.26	2.93	1.09	0.77	3.64	6.26	5.24	0.89
14. Kuda Kongollewa	0	4.62	0.00	0.00	0.00	2.82	1.80	0.00	0.00
15. Ratmalwetiya	0	11.28	0.00	0.36	2.82	10.65	3.80	0.00	0.00

Tank evaluation indicators (maha season).

Tank	Volume (ha-m) Irrigation need (I_t)	Catchment runoff (R_o)	Tank capacity (S_t)	R_o/I_t	S_t/I_t
1. Thimbiri	14.19	70.76	6.13	4.98	0.43
2. Dutu	7.51	48.45	4.52	6.45	0.60
3. Etambagaskada	37.53	232.26	36.09	6.19	0.96
4. Maha Meegaskada	26.58	14.40	6.81	0.54	0.26
5. Kuda Meegaskada	14.07	42.87	5.46	3.05	0.39
6. Maha Divulgaskada	56.29	85.94	24.53	1.53	0.44
7. Kuda Divulgaskada	0	26.72	1.08	–	–
8. Palugolla	9.38	7.17	1.73	0.76	0.18
9. Puhudivula	20.64	20.38	13.28	0.99	0.64
10. Makichchawa	17.22	399.58	41.56	23.21	2.41
11. Nuga	6.26	3.70	0.87	0.59	0.14
12. Vedikkarayage	6.26	6.42	1.68	1.03	0.27
13. Kadawatha	6.26	10.81	2.86	1.73	0.46
14. Kuda Kongollewa	6.26	4.62	2.02	0.74	0.32
15. Ratmalwetiya	8.13	14.46	1.73	1.78	0.21

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P O Box 2075, Colombo, Sri Lanka
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Internet Home Page http:/ /www.cgiar.org/iimi
ISBN 92-9090-345-0
ISSN 1026-0862