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Nature of Small Tank Cascade Systems and a Framework for Rehabilitation of Tanks within Them

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Cover: Artist's impression of a small tank cascade system and its watershed (by D.C. Karunaratne).

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Acknowledgement

The illustration on the SWOT analysis shown in Table 3, as well as the field-testing of the proposed rehabilitation approach on the Maminiyawa cascade outlined in Section 6.2, are studies carried out by Mr. K. Jinapala, Research Associate of IIMI. The authors thank him for this contribution.

CHAPTER 1

Introduction

1.1 STUDY SETTING

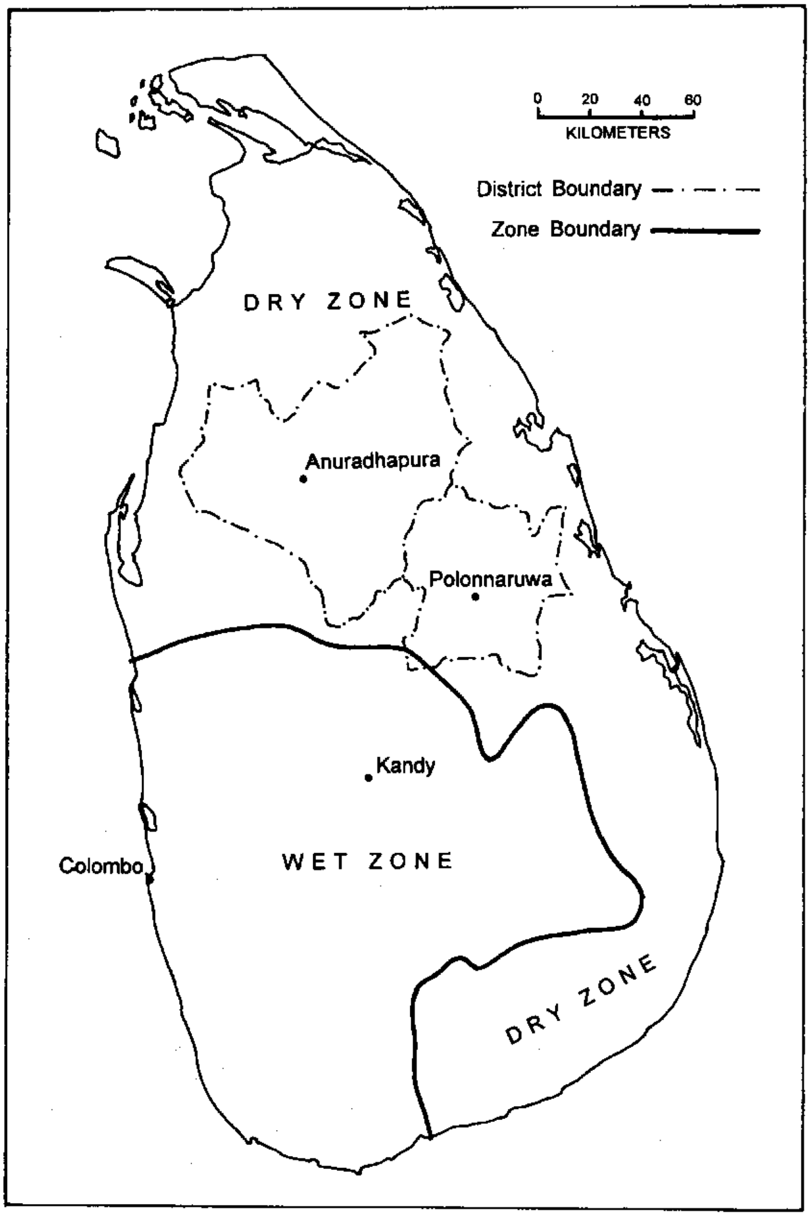
SRI LANKA IS divided into two broad climatic zones, the wet zone and the dry zone. The annual rainfall distribution in both climatic zones follows a bimodal pattern with the wet zone receiving more than 2,500 mm of rainfall, and the dry zone around 1,500 mm. Because of the high yearly variation, the 75 percent probability value of the annual rainfall provides a more reliable statistic of rainfall expectancy, which amounts to approximately 800 mm for the dry zone. The main rainfall season in the dry zone is from October to January and is referred to as the *maha*[1] season with a rainfall expectancy value of 650 mm. The short rainfall season during April-May, which is referred to as the *yala*[2] season, has a rainfall expectancy of 150 mm. During the period late May to September, the dry zone falls within the rain shadow of the major regional southwest monsoon and thus experiences a four-to-five month dry season with strong desiccating winds. Evaporation rates during this period are around 7.0 mm per day and the total annual evaporation is approximately 1,800 mm. Thus the average annual evaporation exceeds the average annual rainfall implying water stress during certain periods of the year.

The study setting relates to the North Central Province (NCP) of Sri Lanka, which is made up of the two administrative districts of Anuradhapura and Polonnaruwa (Figure 1) and is situated entirely in the dry zone. The present study was limited to the Anuradhapura District, which is charac-

1 "Maha" is the typical rice cultivation season in the dry zone that usually coincides with the northeast monsoonal rainfall season between October and February.

2 "Yala" is the shorter cultivation season in the dry zone and it usually coincides with a lower rainfall that occurs during April-May. Rice is not grown in most of the small tanks in the yala season due to scarcity of water.

Figure 1. Sri Lanka: The climatic zones and the two administrative districts of the North Central Province (NCP).



terized by the existence of a large number of small tanks[3] in cascades that are primarily used for irrigated agriculture and domestic uses.

Because of the highly variable nature of rainfall both between seasons and within seasons coupled with the high evaporation rates for more than one third of the year and the paucity of readily accessible shallow groundwater in the hard rock region of the NCP, the small tank surface storage systems provided the lifeblood for human existence. No stable human settlement would have been possible in this environment without recourse to storage of water in these small tanks. The land and water management practices that were refined and perfected over several centuries in order to match the capricious nature of the rainfall with the special geomorphological attributes of the landscape had led to a system of irrigation development described as a "cascading system" by Madduma Bandara (1985). These small tank cascade systems that were constructed in ancient times could be considered as unique irrigation systems with a distinctive assemblage of land uses and agricultural attributes as described by Abeyratne (1956) writing about some basic features of traditional dry zone agricultural systems, and by Leach (1959) writing about the "hydraulic society" of the dry zone.

1.2 SMALL TANK CASCADES

A key feature of the NCP is the presence of a large number of "cascades" of small tanks.

A cascade, according to the definition of Madduma Bandara (1985), is a "connected series of tanks organized within the *micro*-catchments of the dry zone landscape, storing, conveying and utilizing water from an ephemeral rivulet." Minor refinements in terminology to the above definitions have been proposed by Panabokke (in IIMI-SLFO 1994), who suggests the use of the term *meso*-catchment in place of *micro*-catchment so that the former term represents the total watershed area of the cascade of tanks, and the use of *micro*-catchment is restricted to the immediate catchment of each individual minor tank within the cascade. It is also proposed to replace the term *ephemeral rivulet* with either *second-order inland valley* or *first-order ephemeral stream*. It should also be borne in mind that there is no significant

3 Small tanks are those having an irrigated command of 80 hectares (ha) or less.

dry season flow in these ephemeral streams during the period May to October, and again from mid-February to early April.

In a more recent study, Itakura and Abernethy (1993) describe a tank cascade or a chain of tanks as a "series of small reservoirs that are constructed at successive locations down one single common watercourse." The indigenous or folkloristic term for a cascade, according to Tennekoon (1994), is "Ellangava," formed of the two Sinhala words *ellan* and *gava*, *ellan* meaning "hanging," and *gava* meaning "one after another." In these small valleys or meso-catchments, the surface water flows are intercepted by man-made, small earthen bunds to create reservoirs of varying size, which increase in size as one moves downstream of the valley. Any excess water flowing from one tank in such a chain is captured in the next downstream tank. When irrigation is practiced under one tank, the irrigation return flows are captured in the next downstream tank.

Based on a study of the Government Agent's diaries maintained in the Anuradhapura *Kachcheri* (office of the Government Agent) from the middle of the nineteenth century onwards, Tennekoon (1994) concludes that the cascade concept had been well entrenched in the minds of the ancient farmers and water resources managers. He further observes that "one of the cardinal strategies adopted in tank construction in a cascading valley seems to be the strict adherence to: (a) having 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) instituting a regulated flow of water from one tank to another downstream, avoiding a sudden influx of large volumes of water in order to minimize the risk to tank bund breaching."

A schematic representation of a typical small tank cascade system at a scale of 1:50,000 is shown in Figure 2. The main elements that make up a cascade, namely (a) the watershed boundary of the meso-catchment, (b) the individual micro-catchment boundaries of the small tanks, (c) the main central valley, (d) side valleys, (e) axis of the main valley, and (f) the component small tanks as well as the irrigated rice lands are shown in the same figure.

An actual depiction of two adjacent small tank cascades as described by Madduma Bandara (1991) and shown in Figure 3, illustrates the general manner of occurrence of cascades in this landscape. In a similar manner, as depicted for the Toruwewa and Kadiragama cascades in Figure 3 where the main elements of the individual cascades have been identified and demarcated by an appropriate study and interpretation of the 1 inch to 1 mile topographic

Figure 2. Schematic representation of a small tank cascade (scale, 1:50,000).

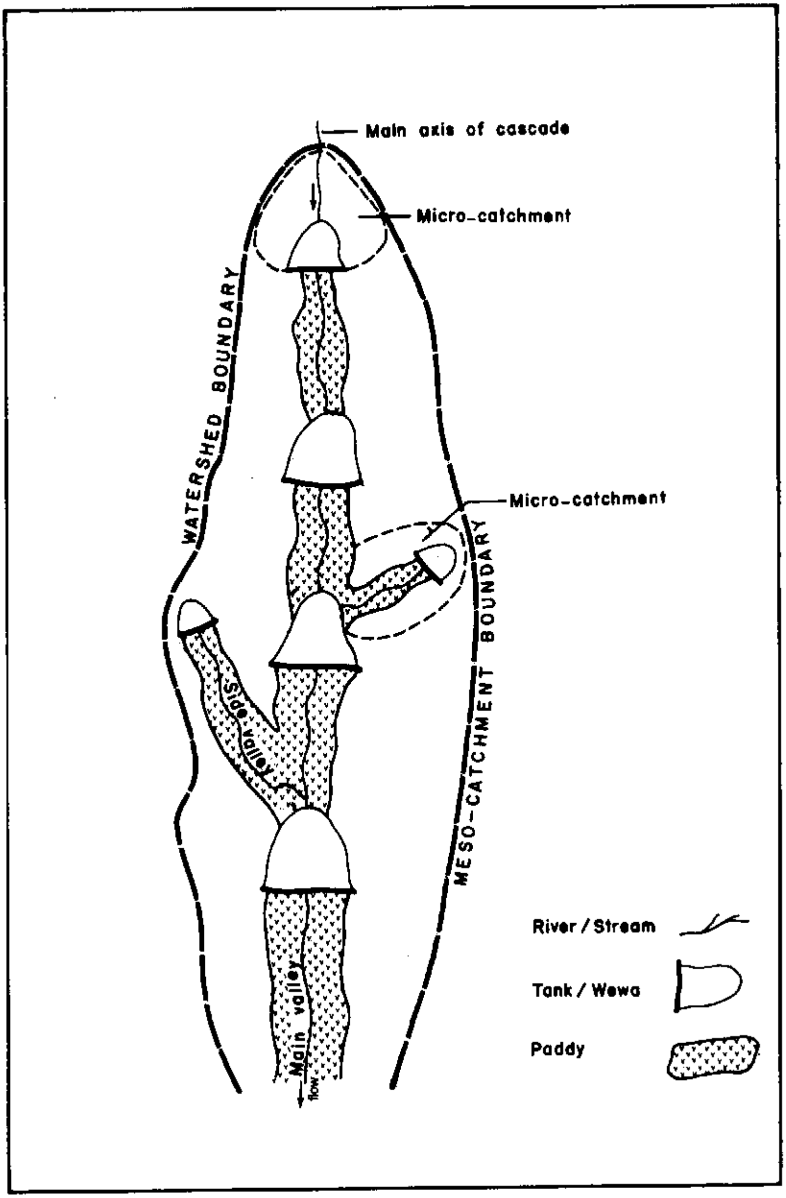
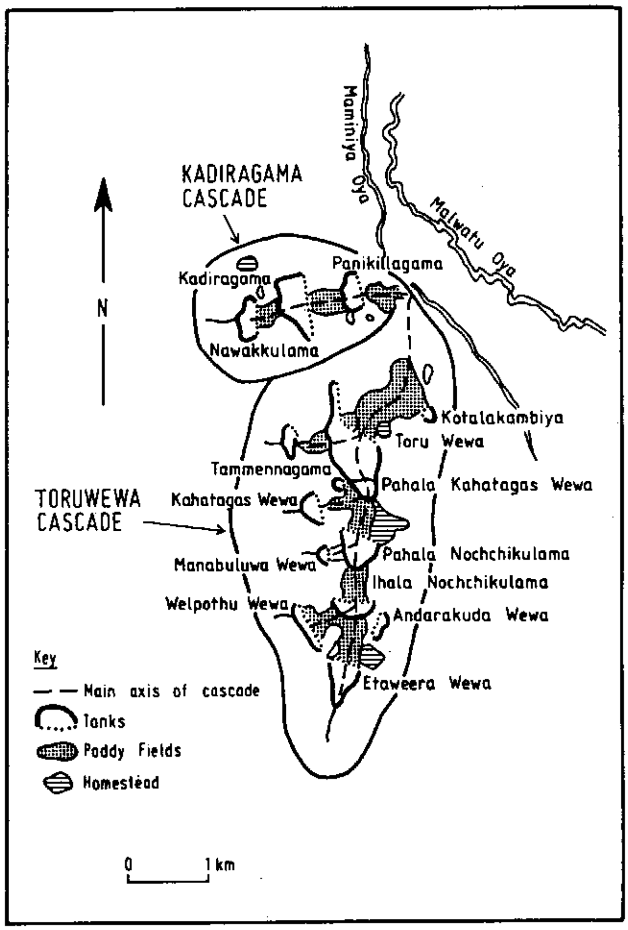


Figure 3. Toruwewa and Kadiragama cascades as appearing on a topographic sheet.



Source: Madduma Bandara 1991.

sheets of the Survey Department of Sri Lanka, it would not be difficult to identifydifficult to identify and demarcate all the component small tank cascade systems that make up the North Central Province (NCP). As proposed by Madduma Bandara, each individual cascade is named after the most prominent tank which occurs within the cascade.

Small tanks in the NCP are clustered into cascades. While a small tank has its own catchment area, a cascade of small tanks can be identified as a cluster of small tanks draining to a common reference point of a natural stream, thereby defining a sub-watershed unit with a definite watershed boundary. A cluster of cascades would form a subbasin of a river, while a cluster of subbasins of a river would form the entire river basin, the basis of clustering being the hydrology of water flow.

Small tanks in a tank cascade are both hydrologically and socioeconomically interlinked. If the hydrology of one or a few tanks is altered by increasing storage capacity, expanding irrigated command area or by diverting water elsewhere from the cascade, the entire hydrology of the cascade is changed. If the cascade is well endowed with water, the effect may not be very significant; but if water is limited in relation to total demand, there may be serious implications in terms of water availability to downstream users. This means that the hydrology of an entire cascade needs to be assessed and understood in order to make the best use of available water resources within the cascade. This exercise is essential before any intervention to any individual tank in the cascade is contemplated.

1.3 SCOPE OF THE STUDY

A review of procedures adopted in the past in small tank rehabilitation in the NCP and elsewhere in the country reveals that tanks are restored[4] and improved[5] under various small tank rehabilitation programs without adequate attention to the overall hydrology of the cascades.

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4 "Restoration" means bringing an abandoned, nonworking tank to working condition by filling breaches in the tank bund (dam), providing spillways, sluices and irrigation canals and undertaking land consolidation and leveling for irrigated agriculture.

5 "Improvement" means increasing storage capacity or expanding the command area of a working tank.

Adoption of a cascade-based holistic approach to water management and small tank rehabilitation has been hitherto difficult due to reasons such as:

a. Lack of a clear technical understanding of the hydrology, the physical characteristics of tank cascades and their interactions and influence on hydrological behavior.

b. Absence of field-tested methodologies, tools and criteria for evaluating the hydrological endowment of cascades and identifying specific tank rehabilitation interventions based on cascade hydrological endowment.

c. Nonadoption of a holistic approach of linking hydrological endowment with rehabilitation interventions and a farming-system approach with suitable institutions.

The criteria for selecting individual tanks for rehabilitation from a list of candidate tanks do not provide adequate guidance for appraising land and water resources development and utilization potential. Also, the present small tank rehabilitation planning process adopted by local irrigation agencies does not include a proper assessment of groundwater potential, recharge, and the possibility for harnessing groundwater to complement rainfall and tank water to increase overall cropping intensity.

Irrigated agriculture under small tanks of small tank cascades (STCs) forms only one component of the activities engaged in by the majority of farmers. Other activities such as *chena* cultivation, home gardening and livestock rearing together with rice and non-rice crop growing in irrigated commands make up their livelihood. Unless the links that exist between irrigated agriculture and other farming activities are clearly understood, and the interactions between these activities and how their interactions influence agricultural decisions are recognized, tank irrigated agriculture per se will not provide the necessary impetus for improving livelihood. Therefore, a holistic approach that considers the hydrological endowment of cascades as well as the interactions of different farming activities within a cascade should form the basis for small tank rehabilitation.

The scope of this study is threefold:

a. To understand the occurrence, distribution, characteristics and hydrology of small tank cascades (STCs).

b. To develop rational criteria for assessing land and water resources, including groundwater potential of small tanks, and for evaluating small tanks for rehabilitation.

c. To propose and to field-test a holistic sociotechnical approach to small tank rehabilitation.

These three study components taken together will help generate a better understanding of STCs and also serve as a guideline for selecting small tanks for rehabilitation.

CHAPTER 2

Small Tank Cascade Systems

2.1 PAST STUDIES ON SMALL TANKS AND SMALL TANK CASCADE SYSTEMS

SCIENTIFIC STUDIES CONDUCTED in this country in the past were essentially confined to individual small village tanks rather than to the whole tank cascade. The best known early example was Kennedy's publication in 1933 titled "Evolution of Scientific Development of Village Irrigation Works." Kennedy observes that prior to this period no attempt had been made to collect scientific statistics of minor irrigation works or to apply anything like scientific principles to their repair and improvement. In his publication, Kennedy proposes four main criteria for the selection and improvement of minor tanks, which involve the collection and analysis of meteorogical and hydrological data, a complete and thorough investigation of the topographical and geological conditions of the site, an evaluation of the benefits in relation to the costs that would be incurred, and the attitude of the beneficiaries under the scheme towards the proposed improvements.

He also outlines the procedures to be adopted in estimating the catchment area, yield, tank capacity and spill discharge in respect of the small village tanks. The special importance and value that he attaches to the 1 inch to 1 mile topographic sheets is best captured in the following extract from his publication that states: "It would be difficult to exaggerate the importance to the engineer concerned with minor irrigation works of the contoured 1 inch to 1 mile topo maps prepared by the Survey Department; and the writer would take this opportunity of recording his grateful appreciation of the indispensable assistance these maps have been to him in his study of this subject." Another statement of Kennedy relating to the use of the topographic sheets is: "Every village irrigation work has an *individuality* of its own, and when located on the topo map, the engineer has next to acquire the *sense and substance* of that individuality."

The 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 description and discussion of some of the basic features of traditional dry zone agricultural systems.

Arumugam's (1957) publication titled "The Development of Village Irrigation Works" could be considered a further consolidation and extension of the earlier studies by Kennedy, while Ponrajah's (1982) publication titled, "Design of Irrigation Headworks for Small Catchments" (up to 20 square miles) could be considered complementary to the studies of both Kennedy and Arumugam.

Among the more significant studies made by social scientists and geographers from the 1950s were those of Farmer (1957), Leach (1961) and Tennekoon (1974) where the focus was yet on the single village tank rather than the whole cascade. The findings of Farmer have made a significant impact on the thinking and approaches of senior administrators and policy-makers concerned with land settlement in the dry zone.

A shift in emphasis from the single small tank to the cascade took place following Madduma Bandara's (1985) approach to the study of catchment ecosystems and village 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. Around the same period, Tennekoon (1986) also stressed the importance of treating the network of tanks in the small valley in their totality rather than treating each reservoir in isolation in respect of irrigation management within the system. This approach was further reinforced by a study conducted by Kariyawasam et al. (1984), which highlighted the impact of unsystematic restoration and development of minor tanks in the Maha Kanadarawa catchment on the seasonal runoff to the tank.

Studies on the very important aspect of the water balance of a small tank were reported by Somasiri (1979) at the Walagambahu village tank located close to the Maha Illuppallama Research Station in Anuradhapura District. This tank has a surface water spread area of 75 acres[6] at full supply level and a storage capacity of 290 acre-feet.[7] Its catchment area is 285 acres and the

6 1 acre = 0.40469 hectare (ha).

7 1 acre-foot = 1,233.5 m^3.

irrigated command area is 32 acres. The water balance of this small tank was studied for four consecutive seasons and it was observed that the percentage catchment runoff during the maha season varies widely, with a high value off 25.4 percent of seasonal rainfall in a very wet maha season compared to 5.2 percent in an average maha season. On the basis of the above figures, the total yield from one square mile[8] of catchment in an average maha season would be about 100 acre-feet, while in a wet maha season it would be about 500 acre-feet. 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 spread.

In further studies, Somasiri (1992) has shown that small tanks with more than 3 acres of catchment per acre-foot of storage capacity can attain full supply level in 40 to 75 maha seasons out of 100; and at least three fourths supply level in 50 to 75 maha seasons out of 100. Therefore, the irrigation potential of minor tanks could be considered as favorable when the catchment area per acre-foot of capacity is more than 3 to 4 acres.

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, on an average, around 150 mm of rainfall is 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 that require around 150 mm of rain to moisten a 1.5 m depth of the soil profile to the field capacity moisture level.

In a more recent study by Somasiri (1993), it is reported that the catchment runoff from a normal dry zone forest, a scrub jungle and an abandoned chena are all very similar and is around 2.0 percent of the maha rainfall; and that runoff is generated only after the soil saturation requirement is met. In contrast, the runoff generated from newly cleared chena land is around 25 percent of the maha rainfall.

All studies reported and commented upon so far have been conducted on individual small tanks rather than on a whole cascade of small tanks. The first water balance study to be conducted on a whole cascade was by Itakura (1994) in the Tirappane cascade located between Anuradhapura and Maha Illuppallama. Results of his studies conducted over four seasons have been reported in Itakura and Abernethy (1993) and Itakura (1994).

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

8 1 square mile = 258.99 ha.

conducted over two maha seasons and two yala seasons, measurements were made of 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 two successive maha seasons, the average runoff percentage was 30 and 12, respectively, and for the two successive yala seasons it was 10 and 4.5, respectively. For the first time a measure of drainage return flow[9] from upstream to downstream tanks was obtained for a total cascade. The proportion of drainage return flow averaged to approximately 23 percent for the tank located midway along the main valley, and 29 percent for the tank located at the lowest end of the main valley. For the tank located at the lower end of the side valley, it averaged to 12 percent. The above values were for the maha season. The return flow values for the yala seasons were zeros.

2.2 GENERAL SETTING OF SMALL TANK CASCADE SYSTEMS

The study was confined to the Anuradhapura District of the NCP because the other district (Polonnaruwa) is dominated by larger irrigation systems and contains only a few small tank cascades (STCs).

The meso-catchment boundaries of all 310 STCs covering the Anuradhapura District, were identified and demarcated on the following one inch to one mile (1:63,360) scale, colored topographic sheets of the areas that make up this district: (1) Vavuniya (2) Padaviya (3) Marichchakaddi (4) Medawachchiya (5) Horowpotana (6) Kala Oya (7) Anuradhapura (8) Kaudulla and (9) Dambulla. Field checks were also conducted to validate the demarcation of the meso-catchment boundaries. It should be noted that there is a very small percentage of small tanks which are not within a cascade but which exit as individual tanks with their own independent micro-catchments. An example is the Pul Eliya tank close to Medawachchiya, studied by Leach (1961) and often cited by social science researchers.

Since it would be impracticable to show this demarcated information of all nine of the above topographic sheets in this publication, two selected topographic sheets, namely, (a) Medawachchiya and (b) Anuradhapura, which contain the highest number of STCs, have been shown in Figures 4

9 Drainage return flow is water delivered to a field that is not consumed by crops, and returns via drains and groundwater for downstream use.

and 5 at a scale of 1:250,000. A general idea of the different sizes, forms and shapes of the respective cascades and the manner of their disposition and alignment in relation to the regional drainage pattern could be readily discerned from Figures 4 and 5.

The natural drainage system of the Anuradhapura District and the distribution pattern of small and big tanks are shown in Map 1 (see attachment inside back cover). The boundaries of the 1:63,360 scale topographic sheets employed in this study are also shown in this map in order to facilitate easy reference and discussion on the regional distribution patterns in different parts of the district. The location and boundaries of the five small tank cascade systems, namely, (1) Maha Kanamulla (2) Tirappane (3) Ulagalla (4) Gangurewa and (5) Thimbiriwewa, that were studied in detail, are also shown in this map.

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 that is characterized by the occurrence of a large number of meso-catchments. All small tank cascades are located within these meso-catchments, and as could be seen both in Map 1 and in Figure 3, these meso-catchments correspond to the second- or third-order inland valleys of the landscape. These second- or third-order inland valleys drain into first-order or second-order streams, which in turn drain into larger third-order streams such as the Maminiya Oya (Anuradhapura topographic sheet) and Kadahatu Oya (Medawachchiya topographic sheet). These then drain into the fourth-order streams or rivers such as Malwathu Oya, Kala Oya and Yan Oya that finally drain into the sea.

As could be observed in Map 1, a considerable degree of variation occurs in both the small tank as well as the small tank cascade densities across the whole district. The highest density of small tank cascades occurs around the upper aspects of the Kanadara Oya and Kadahatu Oya as shown in the Medawachchiya topographic sheet, as well as around the third-order streams that flow into the Maha Kanadarawa reservoir and which are situated in the northeastern portion of Anuradhapura as shown in the topographic sheet. This is in conformity with the normal process of landscape evolution, where a higher drainage density occurs in the upper aspects of the watershed (which decreases as one proceeds to the mid- and lower aspects of the watershed). This is clearly observed in the Kanadara Oya and Weli Oya tributaries of the Malwathu Oya, which are located in the mid- and lower aspects of the watershed as could be observed in the southwestern portion of the Medawachchiya topographic sheet.

Figure 4. *Distribution pattern of small tank cascade systems: The Medawachchiya topographic sheet.*

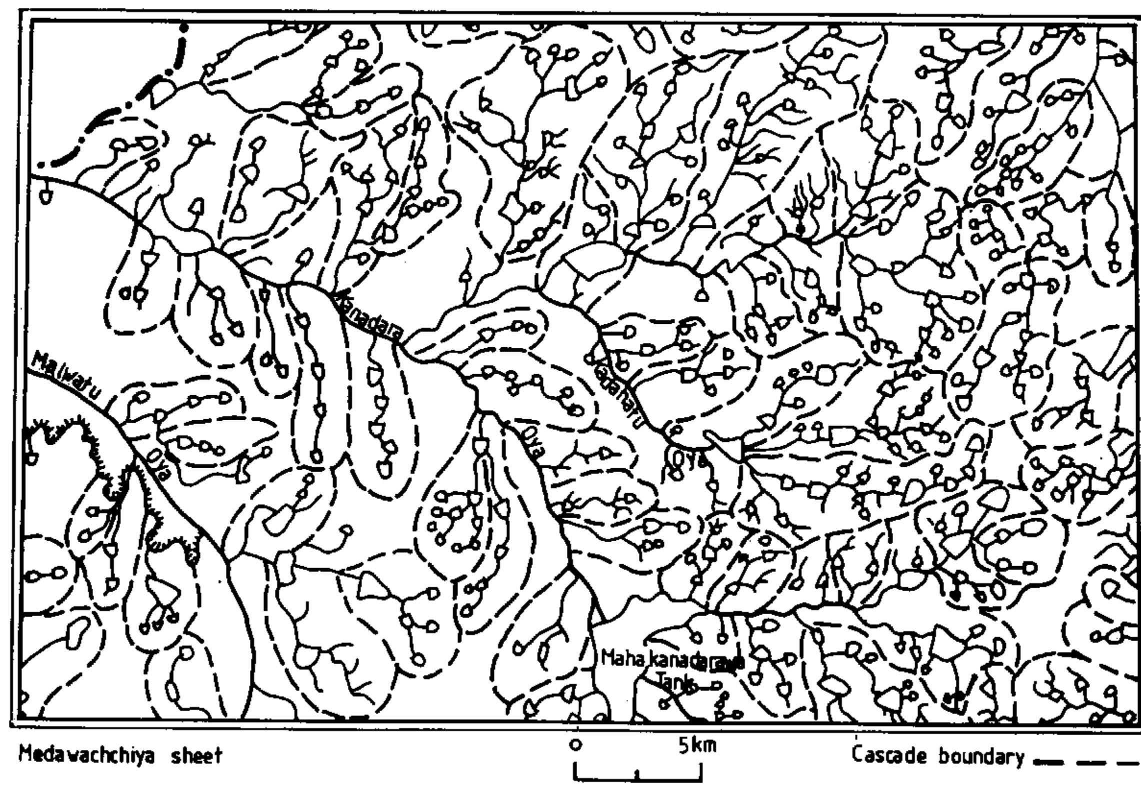
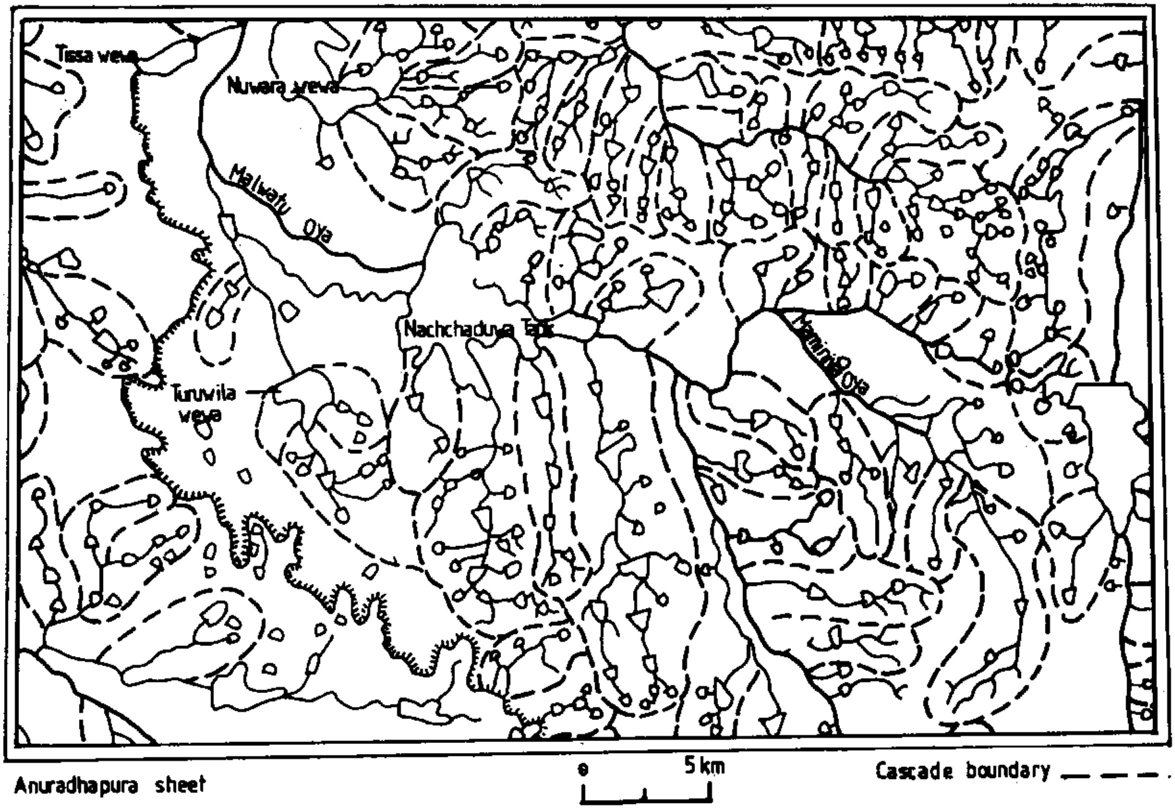


Figure 5. Distribution pattern of small tank cascade systems: The Anuradhapura topographic sheet.



Similarly, a higher density of small tank cascades is observed around the upper aspects of the Malwathu Oya watershed as well as around the upper watershed of the Maminiya Oya and Malwathu Oya branch in the south eastern portion of the Anuradhapura topographic sheet. The density of small tank cascades similarly decreases in the mid- and lower aspects of the main Malwathu Oya, which is a fourth-order stream.

Overall, it could be observed in Map 1 that the *highest* density of small tank cascades occurs in the upper watershed regions of the Malwathu Oya and its main tributaries, namely, Kanadara Oya, Kadahatu Oya and Maminiya Oya, and the upper watershed region of the Mora Oya, which flows northeast. A *moderate* density of small tank cascades occurs in the upper aspects of the Moderagama Aru and Kala Oya, and on the mid-aspects of the main Malwathu Oya, Yan Oya and Ma Oya. A *lower* density of small tank cascades occurs in the lower aspects of all the third- and fourth-order main streams such as Moderagama, Malwathu and Yan Oya.

The most significant observation that could be made in Map 1 is the virtual absence of both small tanks and cascades in the region beyond Mahavillachchiya tank and also beyond the point where the Kanadara Oya joins the main Malwathu Oya as could be seen in the upper half of the Marichchakaddi topographic sheet. The reasons for this phenomenon as well as the factors governing the distribution pattern and tank densities will be discussed in a subsequent section.

2.3 GENERAL CHARACTERISTICS AND PROPOSED TYPOLOGY OF SMALL TANK CASCADE SYSTEMS

In order to identify the main characteristics of the wide range of STCs that occur over the land surface of the Anuradhapura District, first it is essential to demarcate these STCs on a convenient scale that would bring out their main features. This could be achieved by demarcating the catchment or watershed boundary of every individual cascade on the 1 inch to 1 mile colored topographic sheets of the Survey Department that cover this district, and then examining the form and shape of the range of cascades that would then get depicted in two dimensional form on these colored topographic sheets.

Altogether 310 small tank cascades were identified and demarcated on the following 1 inch to 1 mile colored topographic sheets relating to the

Anuradhapura District: (1) Vavuniya (2) Padaviya (3) Marichchakaddi (4) Medawachchiya (5) Horowpotana (6) Kala Oya (7) Anuradhapura (8) Kandulla (9) Dambulla. A general idea of the different sizes, forms and shapes of the respective cascades and the manner of their disposition and alignment in relation to the regional drainage pattern could be readily discerned from Figures 4 and 5 as well as from the demarcations made in the other topographic sheets, as shown in Map 1.

Having examined the size, form, shape and general alignment of the 280 small tank cascades that were demarcated on the colored 1 inch to 1 mile topographic sheets, a two-level typology has been proposed as follows:

a. First level—based on *form* and *size class.*

b. Second level—based on *configuration of the main valley, its main axis,* and *the side valleys.*

The main component elements of the *first level,* i.e., *form* and *size class* are:

Form
- Linear
- Branched
- Form Index

Size Class (total area of meso-catchment)
- Small (< 2,500 acres)
- Medium (2,500–5,000 acres)
- Large (5,000–7,500 acres)
- Very Large (> 7,500 acres)

Examples of linear and branched cascades are shown in Figure 6.

The two parameters used for the proposed typology are (a) the form index, and (b) size class.

The *form index* is the ratio of the overall area of the cascade to its overall length. This value could range from 1.15 to 2.55, and gives a measure of its general shape.

The *size class* refers to the total area enclosed by the watershed or catchment boundary of the meso-catchment within which the cascade is located. The small size denotes an extent of less than 2,500 acres, the medium size between 2,500 and 5,000 acres, the large size between 5,000 and 7,500 acres and the very large size more than 7,500 acres.

The foregoing terms could be considered under the broad terminology of "descriptors" that are commonly used in characterizing natural land systems.

At the *second level*, the main features considered are (a) the nature of the main valley and main axis, and (b) the number of side valleys that enter and join the main valley.

The main valley of a cascade could be long, medium or short, according to the size class of the individual cascade and its form index. However, the more significant property of the main valley and its main axis is the overall slope class of the main axis because this has a close bearing on the hydrology of the cascade. Where the slope class of the axis is gently sloping (0–2.0 percent slope) there is a better retentivity of the water table within the cascade than where the slope class is moderately sloping (2.0–4.0 percent slope).

When there are more side valleys that join with the main valley, the tank density within the overall cascade also tends to increase; and this in turn tends to reduce the ratio of the catchment area to tank water spread area. However, those tanks located at the confluence of two side valleys with the main valley would benefit from an increased inflow.

In sum, it could be stated that hydrologically better-endowed cascades would be those that have: (a) linear or slightly branched form with a form index of more than 1.5; and those that have (b) a gently sloping gradient of the main axis.

In a preliminary selection of cascades for rehabilitation purposes, the above two properties could be employed for a preliminary assessment of the hydrological endowment of the cascade. It should be noted that the slope class of the main axis has to be assessed in the field by a quick traverse from the head end to the tail end of the cascade.

As an illustration, the typology of the five STCs that were studied in detail are given in Table 1. The location of these five STCs and their boundaries are shown in Map 1.

Figure 6. Example of linear and branched cascades.

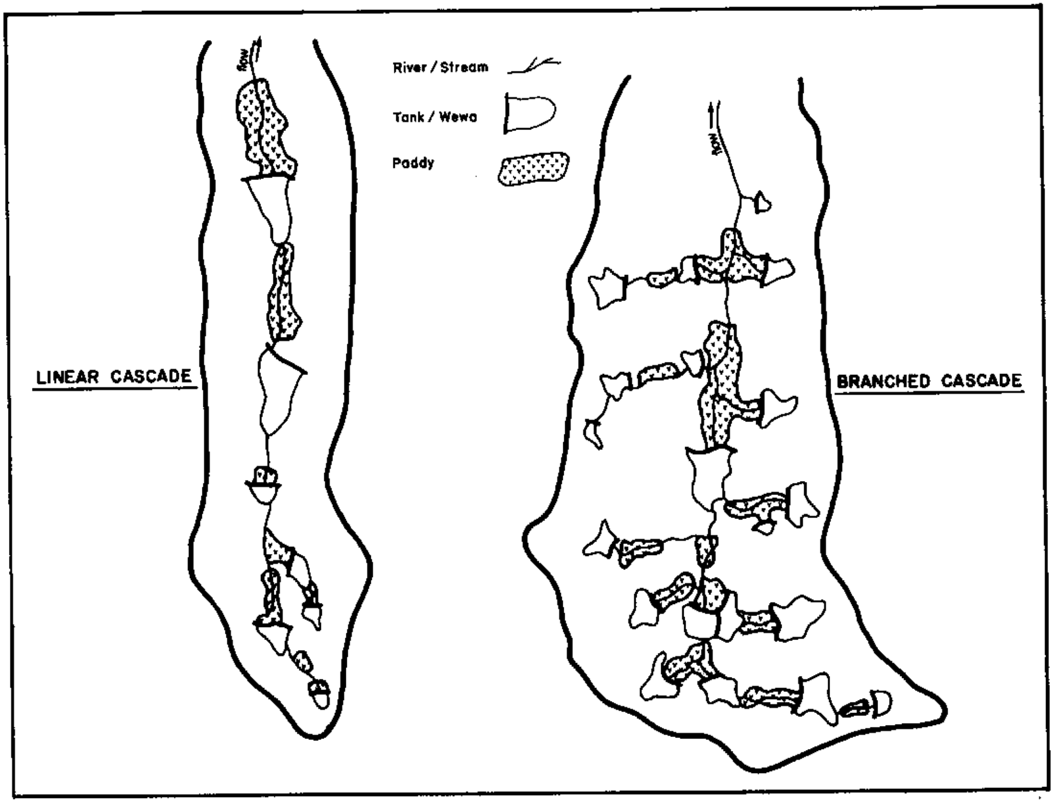


Table 1. Typology of selected small tank cascades.

Name of Cascade	LEVEL 1			LEVEL 2	
	Form	Form Index	Size	Main valley and axis	Side valleys
Tirappane	Linear	1.30	Medium	Moderately straight Moderately sloping	Few
Maha Kanamulla	Branched	2.35	Large	Nonuniform Moderately sloping	Many
Ulagalla	Linear	2.08	Very large	Straight to wavy Moderately sloping	Many
Ganguewa	Branched	2.05	Large	Nonuniform Gently sloping	Few
Thimbiri-wewa	Linear	1.70	Medium	Curved Gently sloping	Few

2.4 FACTORS GOVERNING THE DISTRIBUTION PATTERNS AND DENSITIES OF SMALL TANK CASCADE SYSTEMS

As discussed in the preceding sections, the density of STCs is highest in the upper reaches of the watersheds of the third- and fourth-order streams, and this density decreases along the middle and lower aspects of the main watershed. In the course of field studies, it was further observed that there was a close relationship between the landform type of the area and the density of STC systems.

A landform 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 identified and described earlier (Hunting Survey Coorporation 1963) as the "mantled plain" that usually designates a gently undulating to undulating 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 soil profile material developed in its upper part. Four topographic classes of mantled plain are recognized:

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 STC density is mainly confined to those areas that have a *gently undulating* relief with the surrounding terrain consisting of slopes less than 4 percent. Correspondingly, the lower STC density is mainly confined to those areas that have an *undulating* relief with the surrounding terrain consisting of slopes between 4 and 8 percent.

It should also be noted that when other controlling factors are equal, the amount of seasonal and annual rainfall does have a very significant influence on the density of STCs. This could be clearly observed across the whole of the district on a macro scale where, as the annual rainfall (75 percent probability value) decreases from a high of 882 mm to a low of 611 mm, a corresponding decrease in the STC density is also observed, as seen in Map 1. The values of rainfall for the respective stations are also shown in this map.

Field studies have shown that among the other factors identified as exerting an influence on the density of STCs are the nature of the underlying geology or lithology and the nature of the soil profile overburden. This is best exemplified in the western segment of the Anuradhapura District where the very low tank density (Map 1) is primarily determined by the very porous and highly permeable nature of the soil overburden and underlying lithology that occur in this part of the district.

It is also further observed that the central segment of the Anuradhapura District, which has a comparatively higher tank density, is underlain by the more massive highland series of Precambrian rocks on which is developed a soil catena that has a more compact and less permeable soil profile than the soil catena which occupies the southwestern segment of the district and which has a lower tank density.

Based on the foregoing observations and preliminary studies, it could thus be observed that three main factors govern the distribution patterns and densities of the STC systems in this environment. These are:

1. Amount of annual and seasonal rainfall.

2. Geomorphology of the landscape—landform type.

3. Nature of the underlying lithology and soil overburden.

It should be recognized that further research studies need to be carried out to arrive at a better understanding of how these factors exert their influences individually and collectively, and also how these factors interact to influence the density of STC distribution patterns.

CHAPTER 3

Hydrology of Small Tank Cascade Systems

3.1 HYDROLOGICAL ENDOWMENT

THE HYDROLOGICAL ENDOWMENT of a small tank cascade system (STC) comprises the spatial and temporal distribution of rainfall, and surface water and groundwater potentials. Tools and techniques are available to estimate the hydrological endowment of an STC provided an adequate, reliable database exists. Unfortunately, such databases for STCs are not available, except for rainfall and farmers' experience and knowledge of the hydrological behavior of the cascades in response to rainfall as well as to the operation of the small tanks. In addition, the form, size, disposition and distribution characteristics of STCs also affect the hydrological endowment.

The four main parameters that determine the amount of surface water available to an individual tank of an STC are: (i) direct rainfall, (ii) rainfall runoff, (iii) drainage return flow, and (iv) spill water from the upstream tank. In addition, in special circumstances, a tank may receive supplementary diversions from another tank or a river. Determination of these parameters requires data collection efforts that are time-consuming; for development work and tank rehabilitation in STCs, the implementing agencies need a simple indicator to have a rapid assessment of the hydrological endowment of an STC.

In the search for a reliable and readily measurable index for characterizing the hydrological endowment of a cascade, it was found that the cropping intensity (CI) of the small tanks located within a cascade, averaged over five consecutive maha seasons, provides a reliable and easily measurable integrated value of its hydrological endowment. The CI of any tank is defined here as the area irrigated or cultivated during the maha season divided by the total command area under the tank. The total area includes the old command area termed *puranawela*[10] as well as the newly developed command areas and encroached areas termed *akkarawelas*.[11] Only the maha season irrigated area is considered because there is very little yala season cultivation under these small tanks except in one or two years out of ten when either the annual or the yala season rainfall exceeds the upper quartile value.

The actual average CI for an individual small tank is computed based on the information collected from stakeholders at the village level. Data on the total command area of a small tank and the extent cultivated over the last five consecutive maha seasons are collected through a questionnaire. A time averaged CI is computed based on the data for the previous five maha seasons. It is observed that in a given cascade, the CI of an individual small tank generally increases from the upper end of the main valley towards the lower end. For representing the CI of the whole cascade, a command area weighted average CI of individual tanks is adopted.

The weighted CI for the cascade is computed by weighting the individual tank average CI by the fraction of the command area under the tank and adding it for all the tanks under the cascade. In other words, if CI_i is the average CI of individual tank no i, and a_i is the command area of that tank, then the weighted cropping intensity (CI_w) is given by

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

3.2 ESTIMATION OF SURFACE WATER

Recognizing the highly variable nature of the rainfall both *between* seasons and *within* seasons, a reliable statistic of rainfall expectancy is therefore

10 The original area commanded by the small tank at the time of tank formation is called "puranawela."

11 Under the land allocation policy adopted during the British rule in the 19th century, the command areas of small tanks were expanded without considering water availability and sociological aspects. The newly added area is termed "akkarawela."

considered a prime requirement. Numerous studies have been carried out on this subject area over the last three to four decades by several researchers and all these studies have included the Anuradhapura District. Based on the studies of Panabokke and Walgama (1974) and Kannangara (1984), it is now possible to characterize the different segments of the district in terms of rainfall expectancy values at different levels of probability both seasonally and annually.

A reliable estimate of the runoff generated by a given amount of rainfall from a tank catchment is vital for the selection, planning and design of irrigation tanks for rehabilitation. The Irrigation Department of Sri Lanka adopts a method called "Iso-Yield Method" (Ponrajah 1982) to estimate the seasonal catchment yield from individual small tank catchments, using a set of predetermined iso-yield curves for the NCP. One of the limitations of this method is that the iso-yield curve approach tends to overestimate the catchment runoff. The studies of Somasiri (1979 and 1992), Dharmasena (1991) and Itakura (1994) provide an alternative approach for estimating runoff and seasonal catchment yield. In areas where there are few rain gauge stations, the Thiessen's Polygon method could be employed.

Different runoff estimate models have been suggested by a number of recent research studies. Two models, Maha Kanamulla by Dharmasena (1991) and Nachchaduwa by Somasiri (1992), show that no runoff is generated with the initial seasonal rainfall unless the presaturation requirement of the catchment soils have been adequately met. In respect of the runoff coefficient, the values from these same studies and those of Itakura (1994) range from 0.20 to 0.30 for the maha season as compared with values of 0.25 to 0.35 by the iso-yield approach. It should be borne in mind that the value of the runoff coefficient will be significantly influenced by the nature of the land use and surface cover within the catchment area. Somasiri's studies (1993) show that the runoff generated from newly cleared chena land is in the range of 25 percent of the maha rainfall compared with that of normal forest and scrub jungle, which is around 2.0 percent of the maha rainfall. Furthermore, if the catchment consists of a significant area of rock-knob plain and erosion remnants, the runoff from such land forms is in excess of 90 percent of the incident rainfall. It is important to recognize the distribution of present land use and land forms on the 1:25,000 scale maps of the tank cascade, since it would help make the necessary modification to the value of the ratio that would be finally adopted.

In the final analysis, it is recommended that a runoff coefficient of 0.25 be used with the 75 percent probability of rainfall measured at the closest rainfall station to the tank, with a presaturation requirement of 150 mm deducted.

All of these studies, except that by Itakura (1994), are based on individual tanks. Itakura's study is based on detailed monitoring and measurement of tank water balance components of a less complex linear STC in a research mode. However, application of the tank water balance parameters evaluated by Itakura to the other STCs requires a large set of time series and spatial data, which are not available for the STCs. In view of this, a computer-operated cascade hydrological simulation model is being developed to facilitate the hydrological simulation of any STC. This model is field-tested using the farmers' knowledge and perceptions for understanding and quantifying the hydrological behavior of the tank cascade as a whole.

3.3 ESTIMATION OF GROUNDWATER

Groundwater utilization in STCs has been mainly for domestic use until recent times. During the last 6-7 years, there has been a spurt in harnessing shallow groundwater through dug well (agro-wells) development for agricultural production. Systematic analysis of the groundwater potential needs accurate estimates of rainfall recharge, hydrogeological parameters of the aquifer and fluctuation of the groundwater table. Site-specific data are not available at present. In view of this, a simple method is proposed for groundwater estimation in a cascade system. Computation details are prescribed elsewhere (IIMI-SLFO 1994).

- Prepare a 1:25,000 scale map of the cascade showing the catchment area, tank water spread area, lowland rice area, homestead settlement area, upland chena area and scrub area. Estimate the area of each of the above categories of land use including tank storage.

- Identify the hydrogeological conditions of the meso-catchment such as weathered overburden, number of agro-wells, number of domestic wells used for drinking water, and nature of the groundwater fluctuations over both maha and yala seasons.

- Estimate the recharges from the catchment area, tank water spread area and rice irrigated area using the following relationships: (a) average recharge of 110 mm/year of which 50 percent is available for extraction; (b) average recharge of 160 mm/year inside a tank water spread; and (c) a recharge rate of 150 mm/year for rice irrigated land.

Estimate the recharges contributed by the catchment area, tank water spread area and rice irrigated area. The sum of all these three components will give the total estimate of groundwater available for extraction.

CHAPTER 4

Present Procedures for Small Tank Rehabilitation

4.1 USAGE OF THE TERM "REHABILITATION"

THE TERM "TANK rehabilitation" as used in Sri Lanka connotes one of the following actions.

(a) Restoration of an *old, abandoned* tank together with the reclamation and development of the command area under it.

(b) Restoration of a "*non-working old tank*" where there is already some very limited settlement and cultivation due to the tank bund being breached or the lack of an irrigation delivery system or both.

(c) Improvements to a *working tank* to increase its existing storage capacity or to expand its cultivated command area or both. The improvements include the raising of the tank bund and spill and improving the physical and working conditions of the tank sluices and delivery system.

(d) Refurbishing an existing *working tank* with no modifications to its storage capacity or command area or both. This usually involves carrying out deferred maintenance on the bund and sluice and, at times, strengthening of the bund and spillway.

About four decades ago, minor tank rehabilitation in this country was mainly confined to actions (a) and (b), but the emphasis later shifted to actions (c) and (d), particularly under the Village Irrigation Rehabilitation Project (VIRP) and the National Irrigation Rehabilitation Project (NIRP).

4.2 PRESENT PROCESS OF TANK SELECTION

At present tanks are selected for restoration or rehabilitation from "interest lists" prepared by the Irrigation Department (ID) based on a compilation made jointly by the ID, Department of Agrarian Service (DAS) and the Provincial Irrigation Department (PID). The priority for selection of tanks is, however, strongly influenced by pressure groups that represent a wide range of interests including political considerations and other local influences of several institutions.

It should also be noted that restoration involves bringing an abandoned minor tank to working condition by filling the breaches in the bund, providing spills and sluices and a simple delivery system, while rehabilitation involves repairing or improving an existing working tank in order to improve its performance.

The present process of tank selection involves several successive steps as outlined below:

1. Once the preliminary list of candidate tanks is prepared for consideration for rehabilitation, each tank is appraised by a technical officer. This initial appraisal is called the *Preliminary Investigation* survey or the PI survey.

2. The main purpose of the PI survey is to assess the hydrological potential of the catchment area, the past spilling and cultivation intensities, the additional area that could be brought under cultivation, the present physical status of the tank components, and the impact of restoration or rehabilitation on other tanks located within the watershed. However, it is often the case that the last aspect is usually the least attended to in the PI survey.

3. The PI survey is followed by the execution of the *Full Investigation* survey or the FI survey for those tanks screened through the PI survey methodology. This FI survey includes demarcation of the catchment area, tank bed contour survey, tank bund survey, command area survey and an assessment of rehabilitation improvement.

4. In the final step based on the FI survey, the technical officer is expected to produce a hydrological and technical design for rehabilitation.

4.3 LIMITATIONS OF THE PRESENT PROCESS

The standard approach presently used for the PI survey is the same one that was developed a few decades ago. This purely technical approach is still being used, although the framework and scope of rehabilitation as well as the socioeconomic conditions under small tanks have undergone vast changes. A more rational approach that takes into consideration a proper diagnosis of both technical and institutional problems is therefore required. Furthermore, an adequate understanding of the present use of the resource base, its potential for improved use, together with related constraints associated with small tank rehabilitation is also essential.

A review of procedures of the small tank rehabilitation projects previously conducted in the NCP reveals that the selection criteria used in these rehabilitation projects have not paid adequate attention to the overall hydrology of the tank cascade. The studies also reveal that individual tanks had been selected for either restoration or rehabilitation with little or no attempt made to understand the overall position of these tanks in relation to the hydrological and socioeconomic relationships between the individual tanks located within the tank cascade. No emphasis had been given to assessing the hydrological endowment of the small tank cascade in terms of its CI, which parameter integrates both the land and water resources use of the tank cascades and the individual tanks.

At individual tank level, the general assessment of hydrology, irrigation potential of tanks, cropping patterns and intensities, and organizational aspects had not been made in adequate detail. Also, socioeconomic aspects that affect proper water use and management in the irrigated command areas such as farmer organizations, dispersion and fragmentation of lands in "puranawelas," staggered cultivation of puranawelas and akkarawelas and resulting conflicts, interactions between rain-fed chena cultivation and irrigated rice cultivation in the maha season and production constraints such as lack of credit, extension, seeds, farm power and marketing are also not considered as integral components of small tank rehabilitation. Small tank rehabilitation has been carried out purely in a blueprint approach with little room for farmer involvement or consultation and flexibility for incorporating the lessons learnt during the implementation. A majority of the rehabilitation projects implemented in the past have considered organizational arrangements merely to implement the projects without due considerations and mechanisms to continue with water management and operational practices and procedures introduced by the project.

Although attempts have been made in the past to capture farmers' perceptions for individual tank rehabilitation through participatory techniques and institutional development, this information has not been translated into practical realities through proper technical and economic evaluation. For example, when a farming community wants a tank bund raised or a spillway repaired, the present technical and economic evaluations both facilitate the incorporation of such location-specific proposals. But, when a farming community needs supplementary water supplies through interconnected water conveyance canals from another tank or the diversion of runoff to the river system, that requirement is neither captured through participatory techniques nor incorporated into rehabilitation packages due to the focus being on individual tank rehabilitation rather than on a holistic approach to develop and manage water through rehabilitation of tank and other interventions in the STCs. This is further constrained by the absence of internalization of the cascade concept, mechanisms and institutional devices to capture such farmer perceived proposals and techniques to study the interaction of tanks within a cascade. Therefore, selection criteria for small tank rehabilitation need to be modified and a more rational approach adopted.

4.4 PAST EXPERIENCES AND SHORTCOMINGS

There have been several different projects since the late 1970s that have supported small tank rehabilitation in the Anuradhapura District. The Integrated Rural Development Project (IRDP) for the Anuradhapura District (1979–1984), and the Anuradhapura Dry Zone Agriculture Development Project, ADZAP (1982–1988), were exclusively within the district. The Village Irrigation Rehabilitation Project, VIRP (1980–1990) and the National Irrigation Rehabilitation Project that commenced in 1992 covered several districts of which Anuradhapura was one. A postevaluation study of the IRDP, ADZAP and VIRP projects has revealed that the anticipated results and objectives had not been achieved.

A review of the hydrological design parameters used, especially the 75 percent probability values recommended for the whole of agro-ecological region DL1 by Ponrajah (1982), has revealed that this value underestimates the rainfall potential for tanks in the northeastern segment of the NCP and overestimates the rainfall potential for tanks in the western segment of the NCP.

On the basis of recent investigations conducted by Withana (1994) under the Department of Agrarian Services (DAS), a scheme has been proposed for the identification of village tanks for rehabilitation in the Anuradhapura District. Based on the technical status of the small tank under consideration, three broad categories have been identified, namely, (a) progressive tanks (b) *hold-the-line* tanks, and (c) regressive tanks. In the *progressive* category, the standard technical conditions are satisfied in both the headworks and downstream up to the farm-turnout level. In the *hold-the-line* category, most of the standard conditions are satisfied while the conveyance and distribution network is below the standard condition. In the *regressive* category, only a few standard structures are in position, and both headworks and downstream conditions are not up to standard. For the purpose of tank selection for rehabilitation, the following set of data has to be collected in respect of a village tank: (a) average cultivation success, (b) yield/capacity ratio or the Y/C ratio, (c) tank capacity/command area, (d) spilling history, and (e) position of tank in the cascade. The final selection is made on the basis of a set of comparative scorings given to each of the above components.

It is noted that organizing farmers and forming farmer organizations have become a major intervention in minor tank rehabilitation in the ongoing rehabilitation programs, particularly, with the NIRP. However, a proper assessment of the potential of resource user organization in improving the production and income is not being 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 adopted.

As described in past studies conducted by several authors, it is clearly evident that the cascade concept had been well entrenched in the minds of the traditional farmers and water resource managers from ancient times. The cardinal strategies adopted in tank construction within a cascade valley have been to: (a) have an adequate volume of water in every tank within the cascade even in an year of below-average rainfall, and (b) enable a regular flow of water from one tank to another downstream thus avoiding sudden influx of large volumes of water that may result in tank bund breaching in the lower aspects. In deciding upon the bund heights of the upstream tanks, and the spill levels and sluice diameters of the component tanks within the cascade, one should bear in mind the entire network of tanks located within a cascading valley.

A proper assessment of groundwater availability, groundwater recharge, present rates of abstraction and the critical density of dug wells is not carried out during the present PI and FI investigations. In view of the increasing use of groundwater as a source of supplementary irrigation for other field crops (OFCs) the need for a proper assessment of the groundwater resources hardly needs further emphasis.

CHAPTER 5

Selection Criteria for Tanks in Small Tank Cascades

5.1 CRITERIA FOR SELECTING A TANK FOR REHABILITATION

As a predominating influencing factor, the hydrological endowment is used as a criterion for selecting a tank cascade for rehabilitation. A hydrologically well-endowed cascade is one which has the highest potential for increasing cropping intensity (CI) for the cascade above the present value. In addition, a well-endowed cascade should have a higher frequency and volume of annual spilling of tanks within and outside of the cascade. The potential for increasing CI and the spilling characteristics of cascade tanks can be evaluated through a simulation model mentioned in this paper under the section "Estimation of Surface Water." However, the simulation model requires physical and operational data that may not be readily available in many cascades. Under such cases, the spill characteristics of cascade tanks, especially the volume of spill, together with information of catchment area (CAA) to tank water spread area (WA) ratios for STCs would form the basis for estimating the potential cropping intensity of the cascade. The higher the CAA/WA ratio, the greater the hydrological potential. The difference between the potential and actual observed cropping intensities would then provide a measure of hydrological potential for cascade improvement through rehabilitation. The greater the difference between the potential CI and actual CI, the higher will be the potential for tank improvement.

The following procedure is adopted to identify the CI potential of a cascade.

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 *maha* season for the past five years.

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

c. Ratio of micro-watershed area to tank water spread area, ratio of command area to tank water spread area and special features such as rock outcrops, rock-knob plain (RKP), erosional remnants and quartzitic ridges, etc., and slope of axis and main valley (gently sloping or moderately sloping).

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 socioeconomic.

e. Rainfall pattern and tank spill characteristics (duration, frequency and magnitude).

The analysis of the above set of information will provide a preliminary evaluation of the potential of each tank for improving cropping intensity, which would then allow us to compute the potential CI for the cascade as a whole and thereby select the tank cascade for rehabilitation (IIMI-SLFO 1994).

5.2 PROPOSED CRITERIA FOR SELECTING A TANK FOR REHABILITATION

Once a tank cascade has been selected, the next step is to select the individual tank or tanks for rehabilitation. The criteria for selecting a tank are based on three key indicators:

a. Maha Cropping Intensity (CI).

b. Ratio of Tank Catchment Area (CAA) to Water Spread Area (WA), expressed as (CAA/WA).

c. Ratio of Command Area (COA) to Water Spread Area (WA), expressed as (COA/WA).

The maha CI is one of the basic parameters of tank selection for rehabilitation. The average CI of the tank command area for the last five maha seasons best determines whether a tank is to be selected for rehabilitation. The CI value of the tank integrates both the land and water resources of the tank and the technical, managerial and socioeconomic constraints of the tank and its stakeholders. It, therefore, lends itself as an ideal indicator for tank selection at the highest level.

At the next level, a characterization of the tank in terms of its hydrologic potential (CAA/WA) and adequacy of tank capacity (COA/WA) is a convenient basis for identifying its nature and potential for rehabilitation.

In the final analysis, the interactions between CI and CAA/WA together with COA/WA should be the ultimate selection criteria. For this purpose, CI with four ranges of values are considered, namely:

i. Very close to 1.0
ii. Between 0.85 and 1.0
iii. Between 0.60 and 0.85
iv. Less than 0.6

Accordingly, rehabilitation of any tank should be considered under one of the four categories given below.

Category I

Tanks that have a CI of almost 1.0 and have little hydrologic potential for expanding the command area (i.e., the CAA/WA ratio is much less than 7.5). No improvements, other than essential urgent repairs required to ensure the safety of the tank are considered necessary. In this case, there is no opportunity to increase the CI, unless augmentation of water supply is made from some other source with the commensurate possibility of increasing the command area.

Category II

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

Category III

Tanks which have a 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., the CAA/WA is greater than 7.5 and the COA/WA is less than 1.0). They have adequate hydrologic potential and adequate tank capacity to serve the existing command area. Hence, the low CI may be due to technical or 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 IV

Tanks which have a CI much less than 0.60 and have inadequate hydrologic potential (i.e., the CAA/WA is less than 7.5). No technical improvements can increase the CI significantly due to low hydrologic potential unless there is provision for augmentation from other nearby sources. Such tanks should be considered only for low-cost managerial improvements to increase the CI and/or groundwater development and for augmentation of surface inflow to the tanks through supply canals.

These four categories provide the basic framework for considering any tank for rehabilitation.

Having selected the tanks for rehabilitation by the foregoing process, the next logical step would be to carry out a preliminary assessment of the quantum of rehabilitation work that will have to be carried out. This should be undertaken in a participatory manner and an estimate of the approximate cost of rehabilitation should be made.

5.3 APPLICATION OF THE PROPOSED CRITERIA

The proposed criteria were tested with 10 small tanks (Table 2) that have been rehabilitated. Table 2 indicates that the rehabilitated tanks fall under different categories as described above. However, in the original rehabilitation carried out by the concerned agencies, all of the above tanks have been considered as needing the same type and magnitude of rehabilitation, thereby requiring the same unit cost of rehabilitation. Had the tanks been analyzed according to the suggested criteria, the cost of rehabilitation would have been considerably reduced without sacrificing the performance.

Table 2. Application of the proposed tank selection criteria for rehabilitation.

Tank	CAA (acres)	WA (acres)	COA (acres)	CAA/ WA	COA/ WA	Maha CI	Category
Hiriwadunna	2,560	153	135	16.7	0.9	0.7	III
Punchikulama	1,024	85	170	12.0	2.0	0.5	II or III
Sivalakulama	588	125	109	4.7	0.9	0.3	IV
Maradankadawala	1,018	60	100	16.9	1.7	0.3	II or III
Paluketwewa	640	180	190	3.5	1.1	0.3	IV
Bellankadawala	1,792	172	115	10.4	0.7	1.0	I
Kiribbewa	512	69	100	7.4	1.5	0.7	III
Nelugollakada	1,152	82	148	14.0	1.8	0.6	II or III
Anduketiyawa	384	45	62	8.5	1.4	0.7	III
Pethiyannekada	992	196	210	6.7	1.1	0.5	IV

CHAPTER 6

Proposed Framework and Approach for Small Tank Rehabilitation

6.1 PROPOSED FRAMEWORK AND APPROACH

THE APPROACH SUGGESTED in this study for small tank rehabilitation considers tank rehabilitation in the broader context of land and water resources management of the total area within a given watershed unit, which is the STC in this case. This approach stresses the need for the catchment, tank, highlands, and the command as well as the drainage area of a tank, all to be considered a mosaic of a geographically and socially interwoven watershed unit for integrated rural development planning and implementation.

The overall approach suggested for selecting a small tank for rehabilitation is depicted in the framework shown on page 44. A brief explanatory statement in respect of each of the sequential steps shown in the framework is given below.

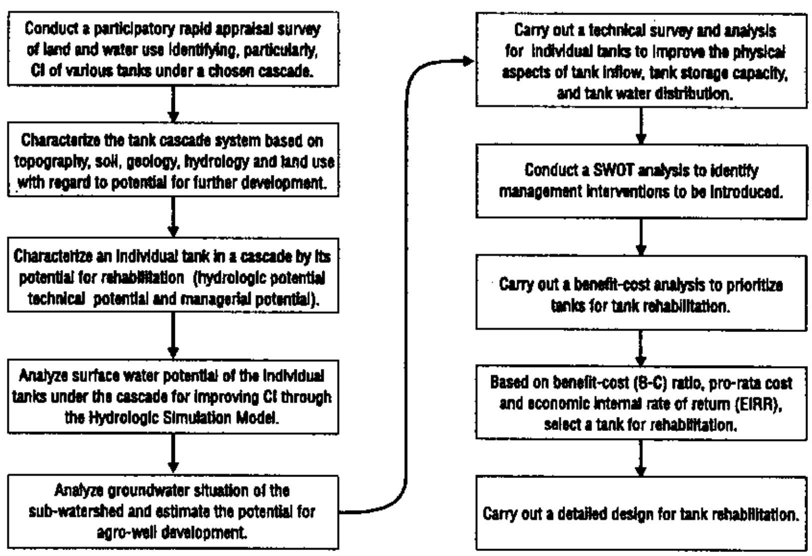
KEY STEPS

Step 1. Conduct a Participatory Rapid Appraisal Survey of the Various Tanks under a Chosen Cascade

The rapid appraisal methodologies employed in this step should provide special emphasis on properly ascertaining the CI for each tank within the cascade by eliciting farmers' recall of memory of the CI for the previous five consecutive maha seasons. Having characterized the cascade by the parameters described under *Factors Governing the Distribution Patterns and Den-*

sities of Small Tank Cascade Systems (Section 2.4) traverse the cascade from head end to tail end noting the following in respect of each tank within the cascade: (a) CI for the past five consecutive maha seasons, (b) the location of tanks within the main valley and side valleys, (c) ratio of micro-watershed area to tank spread area (d) maximum command area cultivated during seasons of very good maha rainfall, and (e) weighted mean of CI for the whole cascade.

A Framework for Small Tank Selection for Rehabilitation



Step 2. Characterize the Tank Cascade System with Regard to Potential for Further Development

Interpretation of the foregoing information will reveal the real potential for further development. This step mostly consists of a participatory approach wherein the technical knowledge of experts is combined with farmers' understanding and experience in characterizing the tank cascade.

Step 3. Characterize the Individual Tank in a Cascade by Its Potential for Rehabilitation

The studies conducted so far have demonstrated that the ratio of the tank catchment area (CAA) to the water spread area (WA) should be higher than 7.5 for a tank to perform well hydrologically. It has also been shown that the ideal ratio of a tank command area (COA) to its water spread area (WA) should be less than 1.0 if the catchment inflow is to be effectively stored in the tank and used for irrigation without excessive losses. These limiting values were deduced using (i) 75 percent probability rainfall for the NCP, (ii) the minimum tank depth required to sustain irrigated agriculture as found from previous research studies (Somasiri 1979), and (iii) comparison of COA and tank storage capacities of a large number of sample small tanks of the NCP. Details of the deduction of the above limiting ratios are available (IIMI-SLFO 1994). These parameters should be assessed with a reasonable level of accuracy at this stage by making use of agricultural base maps of 1:50,000 scale and quick field verification.

Step 4. Analyze Surface Water Potential of the Individual Tank for Improving CI through Simulation Model

Both an analysis of rainfall of the area in which the tank is located and a reliable assessment of the runoff generated by a given amount of rainfall from the tank catchment are necessary; the rainfall over the tank water spread, catchment runoff and the drainage return flow from upstream tanks are the three main parameters that govern the surface water potential of an individual tank. Using a simulation model determine the potential cropping intensity that can be achieved with the available water resource potential. Details of one such model are presented in IIMI-SLFO 1994.

Since there is a significant variation of the 75 percent probability value of rainfall across the NCP, it is recommended that the 75 percent probability value of the closest rain gauge station be employed. In the estimation of catchment inflow/runoff, recent studies show that no runoff is generated with the initial maha or yala rains unless the presaturation requirements of the soils of the micro-catchment area have been satisfied. Based on results from three different sources, a value of 150 mm is adopted for the maha season and 220 mm for the yala season for saturating the soil profile (Dharmasena 1991 and Somasiri 1992). The runoff coefficient will accordingly get modified. Recently conducted simulation studies show that a drainage return flow coefficient of 0.2 could be employed as a reliable estimate of drainage return flow from the upstream rice area (Itakura 1994).

Once a tank has been selected for further analysis based on the observed CI, and the primary nature of the rehabilitation has also been identified, then one has to identify the most cost-effective combination of hydrological, technical and managerial improvements required to increase its CI.

Step 5. Analyze Groundwater Situation of the Sub-Watershed and Estimate the Potential for Agro-Well Development

The manner in which the groundwater situation in a cascade system could be estimated is described under the section on estimation of groundwater resources (Section 3.3).

Step 6. Carry Out a Technical Survey and Analysis for Individual Tank Improvement and Water Distribution

This component would include four main study areas: (a) technical analysis, (b) water resources analysis, (c) management analysis, and (d) socioeconomic analysis.

The technical analysis should have a rapid assessment of technical aspects of the tank catchment, tank bed, tank bund, sluices, spill, distribution system and irrigation system management. The proposed rapid assessment is a substitute for the PI surveys conducted at present. The water resources analysis will include catchment area, tank spilling and filling frequency, groundwater use and cultivation history. The management analysis would essentially be focused on how best the sequential availability of all three water resources components, namely, rainfall, surface irrigation supply and groundwater, is matched with cropping pattern and cropping sequences for maha and yala seasons. The socioeconomic analysis will include a rapid assessment of the production structure, production constraints in the irrigated command, and rain-fed, chena and dug-well components of the farming system. Details of the rapid assessment are available (IIMI-SLFO 1994).

Step 7. Analysis to Identify Appropriate Management Interventions

A diagnosis of the existing strengths and weaknesses would provide the basis for identifying both future opportunities and threats. Analysis of strengths, weaknesses, opportunities and threats (SWOT) will lead to an identification of the existing strengths and weaknesses, the analysis of which will lead to (a) an identification of areas for which interventions are required, and (b) formulation of appropriate intervention strategies. Details of SWOT analysis are available (IIMI-SLFO 1994). An illustrative outcome of SWOT analysis for tank rehabilitation planning is presented in Table 3.

Step 8. Benefit-Cost Analysis, Pro-Rata Costs and EIR

Since the pro-rata cost of rehabilitation, the benefit-cost ratio (B-C ratio) and the internal rate of return (IRR) will be the three main parameters that will be ultimately used for selecting a candidate site for small tank rehabilitation, the above set of economic analyses should be carried out in order to make the final decision.

6.2 Field Testing of the Proposed Rehabilitation Approach

This section briefly presents a case study of field-testing of the above proposed approach on 15 sample STCs in the NCP.

"Maminiyawa cascade" is one such cascade located in one of the upper sub-watersheds of the Malwathu Oya river basin of the NCP. The Malwathu Oya river basin as well as its component sub-watersheds and cascades were demarcated on 1:63,360 topographic maps. The Maminiyawa cascade, including its tank irrigated area, homesteads and catchment areas were traced on to a separate field working map. A field team comprising an institutional development specialist, irrigation engineer and field assistants visited the cascade and ascertained the details of tanks and thus developed a detailed

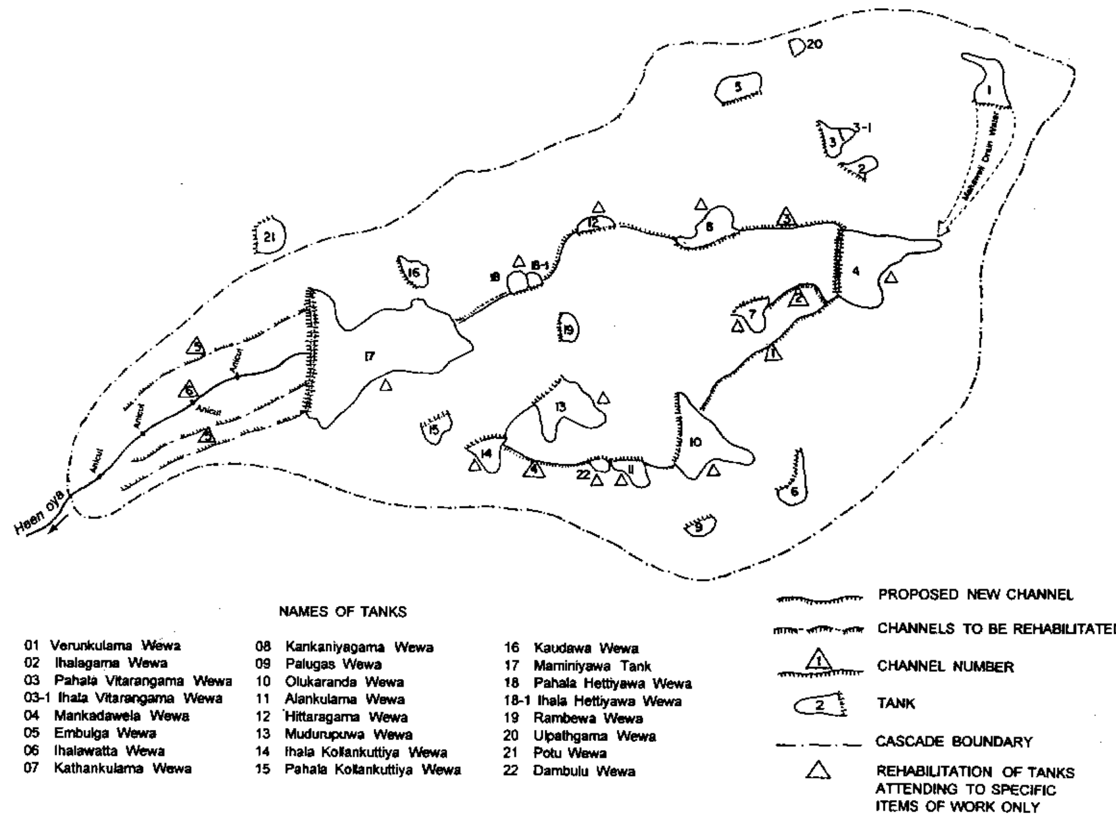
Table 3. Illustration of SWOT analysis.

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 network is not adequate. Existing canal network is dilapidated.	* Water availability in the tank. * Possibility of improving canal system. Allow local catchment inflow by changing a few critical culverts that 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 in akkarawela. * Lack of agri-extension facilities. * There is no system for water management. * Delay in land preparation. * Low interest of group of far ers in cultivation in puranawela. * Low yield.	* Potential for organizing farmers. * Potential for motivating farmers to cultivate puranawela. * Potential for improving water management practices. * Potential for bringing farmers to do timely cultivation. * Potential for increasing yield.	* Domination of akkarawela farmers in water use. * Farmer priority for chena. * Further fragmentation of land.

map through participatory rural mapping and consultation. Three levels of consultation were held: first, at individual tank level; second, at the sub-cascade level involving a few tanks, and finally at the cascade level. Farmers' experience and knowledge on the hydrological behavior of the cascade, operational constraints, reasons for low cropping intensity and potential opportunities for improving the CI through tank rehabilitation and inter-tank water conveyance and augmentation were successfully captured by this methodology. In addition, the information on chena-rice cultivation interactions, production constraints, as well as opportunities and threats faced by farmers in the locality were also appraised and noted to alleviate constraints and promote production as well as the conservation of their resources base. A typical water resources development plan proposed and developed by the farmers through consensus building using participatory appraisals and mapping is presented in Figure 7. These proposals are then tested and validated through the cascade simulation model. The development plan expresses the farmers' experiences, perceptions, knowledge, wisdom and needs in respect of water management and improving cropping intensity of cascade.

In the first step of the technical appraisal of the farmers' development plan, minor modifications to the farmers' development plan may be done on the basis of hydrological simulation. The next step would be a quick appraisal of the technical feasibility of the proposals by engineers during which phase the proposals are technically evaluated. The third step is a quick appraisal of the cost of the proposals in order to evaluate the pro-rated costs so as to approve the proposals.

Figure 7. Maminiyawa Cascade—proposed water resources development plan.



CHAPTER 7

Summary and Conclusions

Small tank cascades totaling 310, covering the Anuradhapura District in the North Central Province of Sri Lanka were identified and demarcated on colored 1 inch to 1 mile topographic sheets. The distribution pattern of the small tank cascade systems including the individual component small tanks as well as the natural drainage systems for the Anuradhapura District are shown in Map 1. The highest density of small tank cascades is observed to occur around the upper aspects of the watersheds of the third- and fourth-order streams; and this density decreases along the middle and lower aspects of the watershed. This is in conformity with the normal processes of landscape evolution where a higher drainage density occurs around the upper aspects of the watershed and decreases as one proceeds to the mid- and lower aspects of the watershed.

Based on the present preliminary studies, it is observed that the three main factors which govern the distribution patterns and densities of the small tank cascade systems of the district are: (a) the amount of annual and seasonal rainfall; (b) the geomorphology of the landscape; and (c) the lithology of the underlying strata. A two-level typology has been proposed, where the first level is based on form and size class of the cascade, and the second on the configuration of the main valley and main axis and the disposition of the component side valleys. The cropping intensity of a small tank cascade based on the weighted average value of five consecutive maha seasons has been found to provide a reliable and easily measurable integrated measure of its hydrological endowment. The above factors were taken into consideration while selecting a cascade for its hydrological potential.

The procedure adopted at present for small tank rehabilitation under cascades is the same as that developed by the Irrigation Department a few decades ago. A more rational approach that takes into consideration a proper diagnosis of both technical and institutional problems is therefore required. The approach suggested in this study considers tank rehabilitation in the broader context of land and water resources management of the total area within a given meso-catchment or watershed unit. This approach stresses the need for the catchment, tank highlands and the command as well as the drainage area of a tank, all to be considered a mosaic unit for integrated development. A framework for small tank selection for rehabilitation has been proposed and an explanatory text for each of the sequential steps shown in this framework has been provided. This analysis is mainly based on the hypothesis that a high hydrological potential of a tank cascade is a prerequisite for individual tank improvement within that cascade.

The criteria for selecting tanks for rehabilitation are based on three key indicators: (a) Maha Cropping Intensity (CI); (b) Ratio of Tank Catchment Area (CAA) to Water Spread Area (WA); and (c) Ratio of Command Area (COA) to Water Spread Area (WA).

The proposed method has been tested for its cost-effective rehabilitation in ten of the tanks that underwent rehabilitation in the recent past according to the presently adopted procedure. We believe that this procedure will result in cost-saving as well as in improving the performance of rehabilitated tanks. The proposed method was also tested in 15 cascades and a typical water resources development plan proposed and developed by the farmers through consensus building using participatory appraisal and mapping is presented.

The proposed method is accepted for implementation by the Irrigation Department and the related agencies, the Government of Sri Lanka in an Area Development Project being planned for the NCP with funding provided by the Asian Development Bank (ADB) and the International Fund for Agricultural Development (IFAD).

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