THE NATURE AND PROPERTIES OF SMALL TANK SYSTEMS OF THE DRY ZONE AND THEIR SUSTAINABLE PRODUCTION THRESHOLDS

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Nature and Properties of Small Tank Systems

Past Scientific Investigations

I have discussed the past scientific studies made by several researchers since 1950 in my recent publications on this subject (Panabokke 1996 and 1999). I wish to however draw your attention to a pioneer and classical contribution made as far back as in 1936 on the Evolution of Scientific Development of Village Irrigation Works, by a very distinguished former Director of Irrigation J. S. Kennedy (1936) in his Presidential address to the Institute of Engineers and published in the Transactions of the Institution. Two very important statements stand out in his address which are as follows:

> *"Science is systematic and formulated knowledge, and when the knowledge that has been systematically accumulated on a subject, by trained observation and experiment, is fully organized, the subject becomes amenable to quantitative treatment."*

> *"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 main aim of my past and recent studies on small tank systems has been the systematic formulation of knowledge by observation and experiment, with a view to subjecting this knowledge to quantitative treatment; and also to search for that elusive **sense and substance** of the individuality of the range of small tank systems in the dry zone landscape.

Essential Nature of Small Tank Cascade Systems

It is now clearly recognized that the large number (more than 15,000) of small tanks that are distributed across the undulating landscape of the dry zone are not randomly located and distributed as commonly perceived; rather they are found to occur in the form of distinct cascades that are positioned within well defined small watersheds or meso-catchment basins. A cascade of tanks is made up of 4 to 10 individual small tanks, with each tank having its own micro-catchment, but where all of the tanks are situated within a single meso-catchment basin. These meso-catchment basins could vary in extent from 6 to 10 sq. miles, with a modal value of 8 sq. miles in the North Central Province region.

A schematic representation of a typical **small tank cascade system** at a scale of 1:50,000 is shown in Figure 1. 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. These small tanks form a series of successive water bodies along small water courses and are called a "**cascading system**". The advantage of such a system is that excess water from a reservoir along with the water used in its command area is captured by the next downstream reservoir, and is thus put to use again in the command area of the second reservoir. This water is thus continuously recycled. This system helps to surmount irregularly distributed rainfall, non-availability of large catchment areas and the difficulty of constructing large reservoirs.

Three small tank cascades close to Anuradhapura that lie adjacent to each other and are easily observed on the Maradankadawala-Tirappane road with the aid of the 1 inch to 1 mile topo sheet of Anuradhapura are depicted in Figure 2. The kilometer sign posts shown in this map-figure will help the reader to locate himself when travelling on this road, and thus enable him to easily locate the tank cascade systems on the ground.

Distribution Patterns

The setting and distribution pattern of small tank cascades across the Rajarata landscape has been described by Panabokke (1999). Altogether a total of 457 small tank cascades have been identified and demarcated over 50 sub-watersheds that make up the nine river basins of the Rajarata. A summary statement of the total number of sub-watersheds present within each main watershed, together with the total number of cascades present within each sub-watershed is given in Table 1.

Table 1. Summary Statement of the Distribution Pattern

Main Watershed Basins	Number of Sub-watersheds	Number of Cascades
MAL – Malwathu Oya	15	179
K – Kala Oya	12	68
Y – Yan Oya	7	74
MA – Ma Oya	4	40
MO – Modaragam Ara	3	42
PAR – Parangi Aru	4	34
PAN – Pankulam Ara	3	11
KO – Koddikkaddi Ara	1	8
ME – Mee Oya	1	1
Total	**50**	**457**

It should be noted that there are a small percentage of small tanks that do not occur *within a cascade, but as individual tanks with their own independent micro-catchment.* A

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SCHEMATIC REPRESENTATION OF A SMALL TANK CASCADE

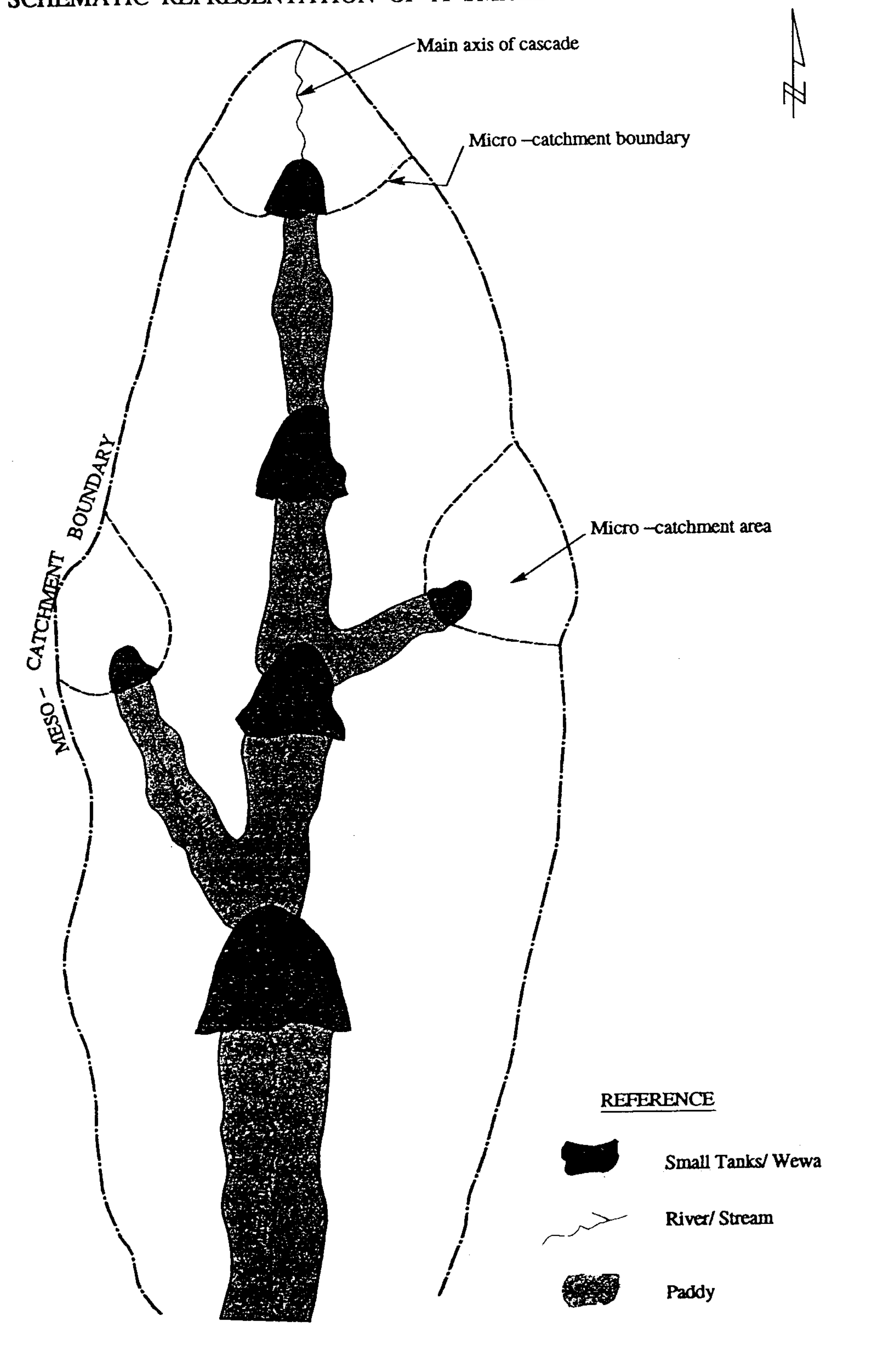


Figure 1

Prepared by Environment & Forest Conservation Division, Mahaweli Authority of Sri Lanka, Polgolla.

SCHEMATIC REPRESENTATION OF A SMALL TANK CASCADE

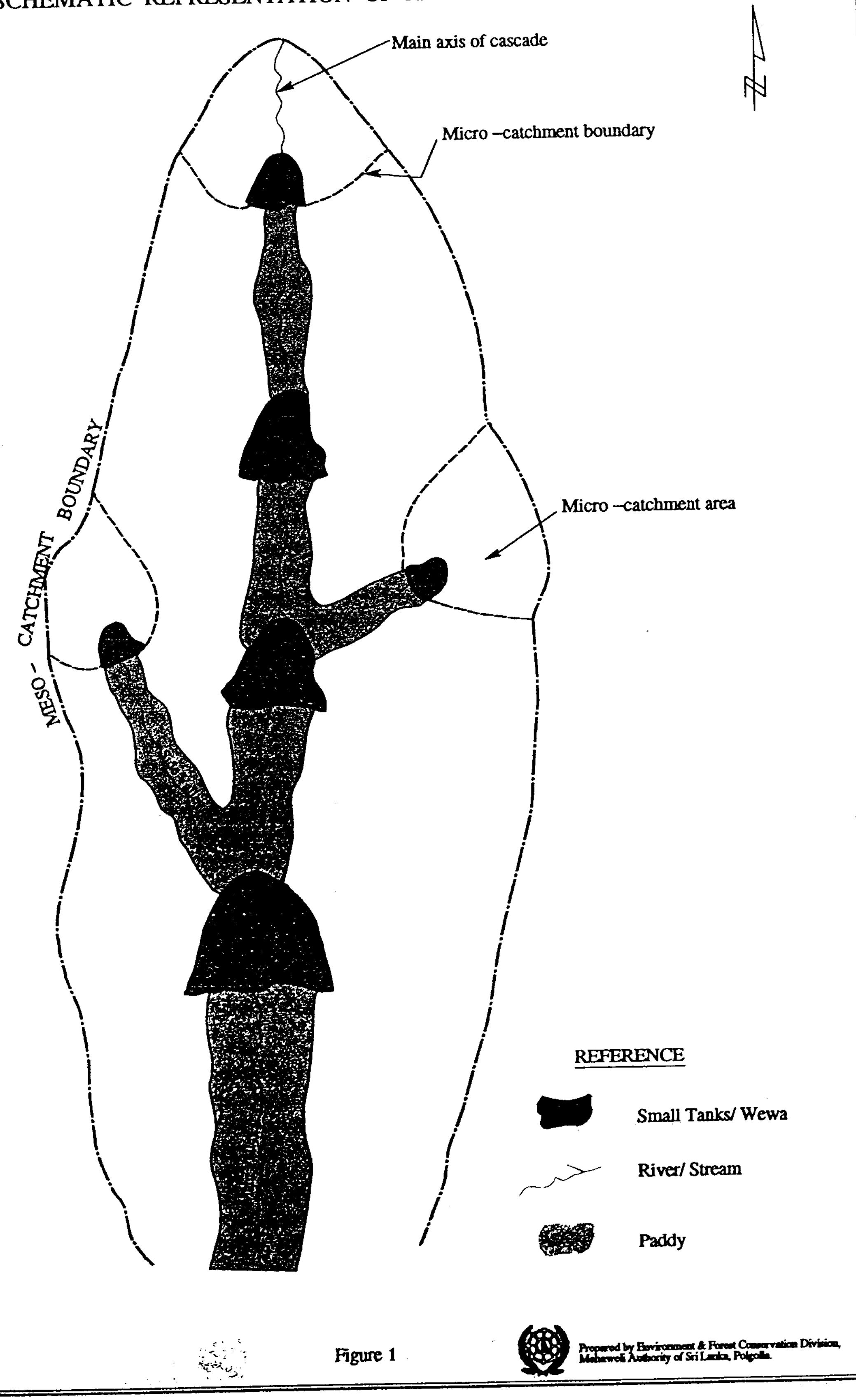


Figure 1

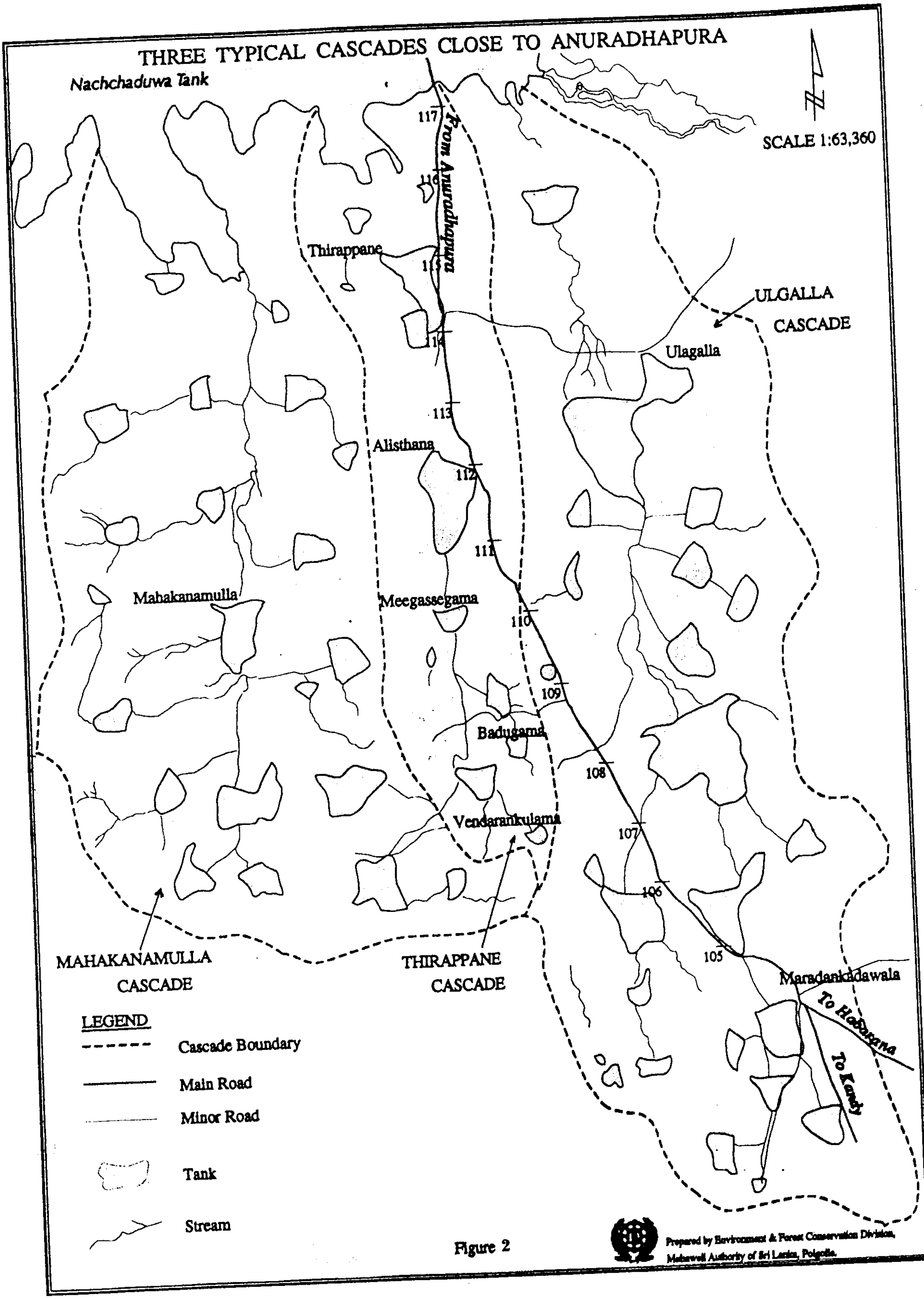

THREE TYPICAL CASCADES CLOSE TO ANURADHAPURA
Nachchaduwa Tank
SCALE 1:63,360
From Anuradhapura
117
116
115
114
113
112
111
110
109
108
107
106
105
Thirappane
Alisthana
Meegassegama
Badugama
Vendarankulama
Mahakanamulla
Ulagalla
ULGALLA
CASCADE
Maradankadawala
To Habarana
To Kandy
MAHAKANAMULLA
CASCADE
THIRAPPANE
CASCADE
LEGEND
Cascade Boundary
Main Road
Minor Road
Tank
Stream
Prepared by Environment & Forest Conservation Division,
Mahaweli Authority of Sri Lanka, Polgolla.

Figure 2

well known example being that of the Pul Eliya village tank close to Medawachchiya studied by Leach in 1956, and often cited by social science researchers.

As shown in the master map titled "The Hydrography of the Rajarata" (Panabokke 1999) a high density of small tanks occurs in the upper watershed regions of the main river basins such as the Malwathu Oya, Kala Oya and Yan Oya, as well as the major tributaries such as the Maminiya Oya, Kanadara Oya and Kadahatu Oya. This conforms to the normal process of landscape evolution where a higher drainage density occurs in the upper aspects of a watershed, thus resulting in a higher tank density in its upper reaches. By contrast a lower density of small tank cascades occurs across all the lower reaches of the sub-watersheds of the Malwathu Oya, Kala Oya, Yan Oya and Moderagam Ara.

The natural drainage system and the small tank distribution pattern of the Anuradhapura district is depicted in Figure 3. It could be observed from this figure that the highest small tank density occurs around the Kanadara, Kadahatu and Rampathvila Oyas which are located on the main watershed divide that separates the western flowing and eastern flowing main river systems. This region, accordingly, constitutes the heart of the Rajarata tank civilization or the "Wew Bendi Rajje" described by Tennakoon (1999).

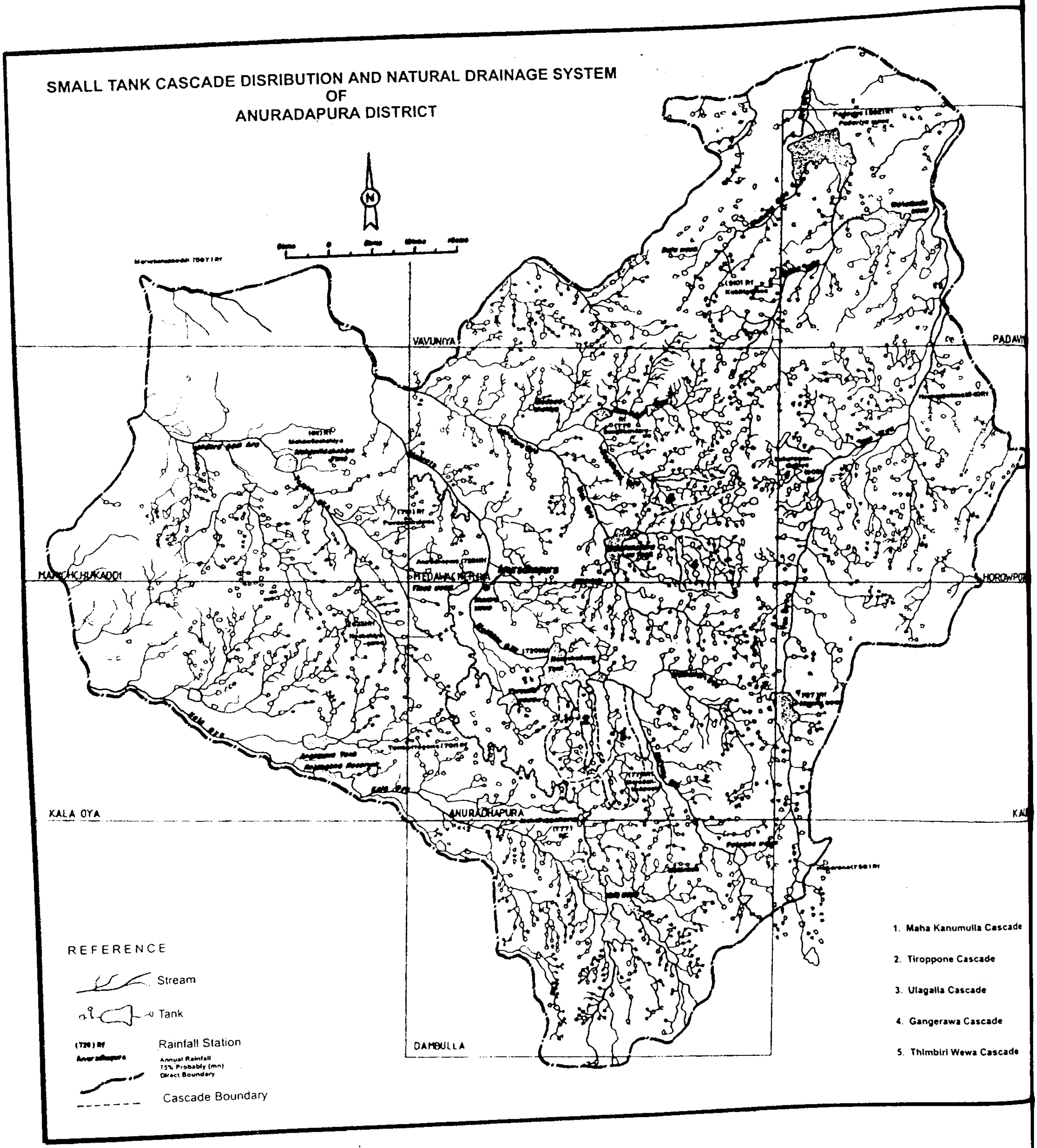
A further important feature of this particular region is the virtual absence of abandoned tanks. There is also an oral tradition in this region that it was never totally abandoned during the dark period between the thirteenth and nineteenth centuries, and it is said to have had an unbroken history of continuous settlement over the last 2000 years. It is also claimed that during the heyday of the Anuradhapura civilization this region had a very close symbiotic association with the main capital city, and it was also its main source of food sustenance.

Range in Size, Shape, Form – Typologies

As stated earlier by Kennedy (1936), "when the knowledge is fully organized, the subject becomes amenable to quantitative analysis". We have now reached a stage whereby the cascades can be characterized in terms of their size, shape and form, thus leading to various forms of quantitative analysis and development of typologies. It should be noted that cascades lend themselves better to quantitative analysis than the individual small tanks because a cascade is closer to a natural system than an individual small tank.

In terms of **size** the following **size classes** of cascades are recognized. The size class denotes the total area of the meso-catchment of the cascade.

Small	< 2,500 acres
Medium	2,500 - 5,000 acres
Large	5,000 - 7,500 acres
Very Large	> 7,500 acres


SMALL TANK CASCADE DISRIBUTION AND NATURAL DRAINAGE SYSTEM
OF
ANURADAPURA DISTRICT
N
VAVUNIYA
KALA OYA
ANURADHAPURA
DAMBULLA
REFERENCE
Stream
Tank
Rainfall Station
Cascade Boundary
1. Maha Kanumulla Cascade
2. Tiroppone Cascade
3. Ulagalla Cascade
4. Gangerawa Cascade
5. Thimbiri Wewa Cascade

In respect of **shape and form**, the form index of a cascade could be expressed as the ratio of the overall area of the cascade to its overall length. This value could range from 1.15 to 2.55 and it gives a measure of its general shape which could then be linked with its general geometry that could be linear, branched or angular. Examples of cascades of different size, shape and form are shown in Figure 4.

Panabokke (1998, unpublished) has measured a total of 50 cascades for their (a) area, (b) form index, (c) cropping intensity, (d) ratio of tank catchment area to tank command area; and he observes a strong correlation between the area of the cascade and its form index; and a weak quantitative but noticeable qualitative relationship between the drainage density and cropping intensity, and also between the drainage density and the ratio of cascade area to tank area.

Merits of Considering Tank Cascade Systems over Individual Tanks

As seen in Figure 1, the hydrology of the whole meso-catchment within which the individual small tanks are located has a specific significance in as far as it relates to the hydrology of the individual tanks themselves. For example, while the small tank located in the uppermost aspect of either the main valley or the side valley receives its runoff exclusively from its own micro-catchment, the other tanks located mid-way or at the lower aspect of the main valley will receive their runoff from a larger catchment together with the drainage flow from the tank immediately above it. Thus the hydrology of the lowermost tank within the cascade will be determined by the runoff generated by the whole meso-basin together with the drainage flows from all the tanks and paddy fields located above it.

As shown by Panabokke (1998), the shallow regolith groundwater is located in the lowland, which generally lies adjacent to and athwart the lowermost member of the soil catena. The groundwater regime is therefore confined to a specific topographical location within the cascade, and not at random across the landscape as commonly envisioned. Panabokke (1998) has also shown that the safely exploitable groundwater in the dry season is mainly confined to the areas immediately adjacent to the main axis of the cascade. Senaratne (1996) has developed a methodology to estimate the carrying capacity of agrowells within a cascade.

Quantitative Criteria and Hydrological Endowment

Two quantitative parameters that have a close bearing on the hydrological characteristics of a cascade are:

(a) the ratio of the total catchment area of cascade (CAA) to the total water spread area of all tanks located within the cascade (WA), and
(b) the ratio of the total command area under all the small tanks (COA) to the total water spread area (WA).

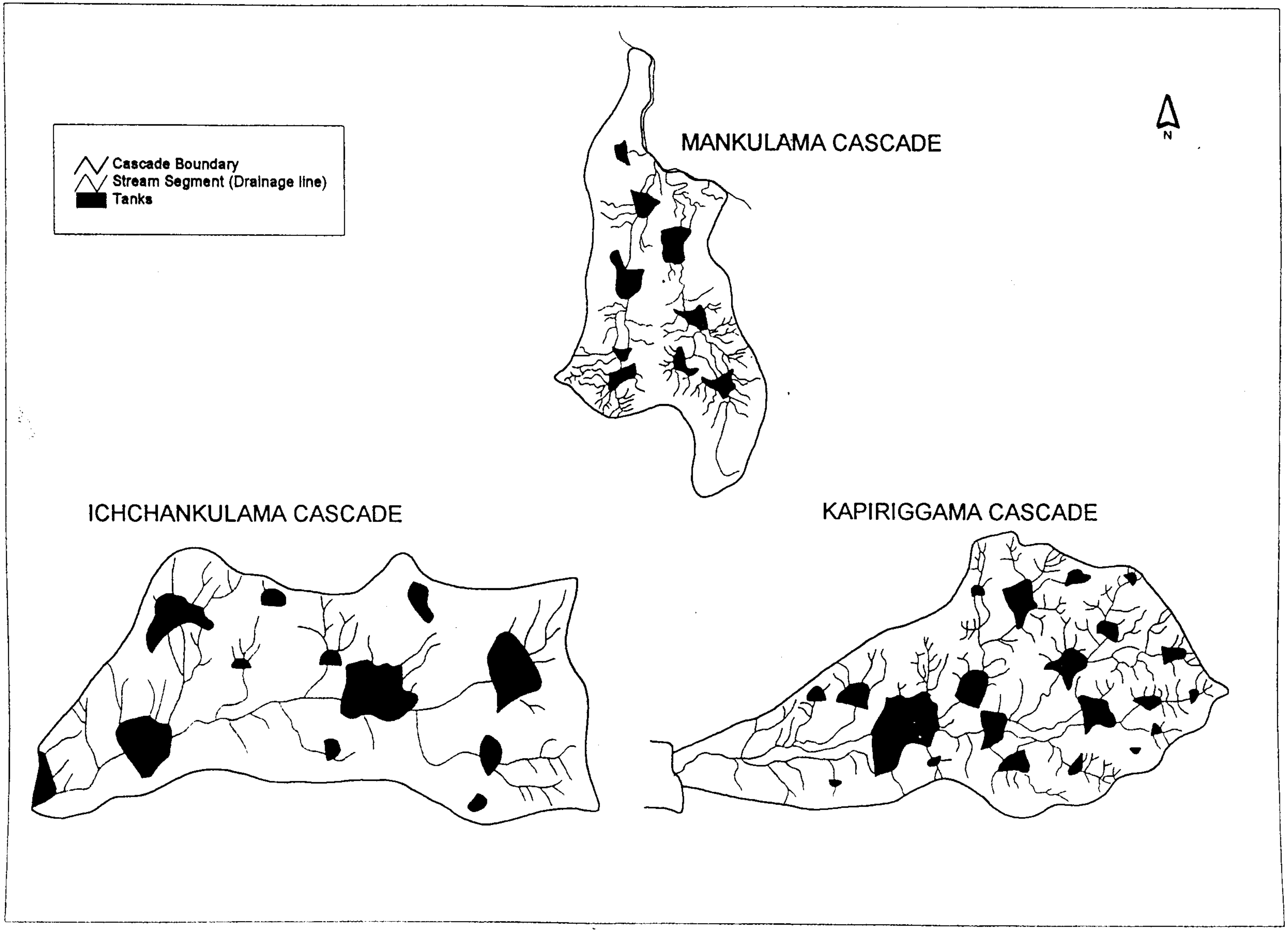
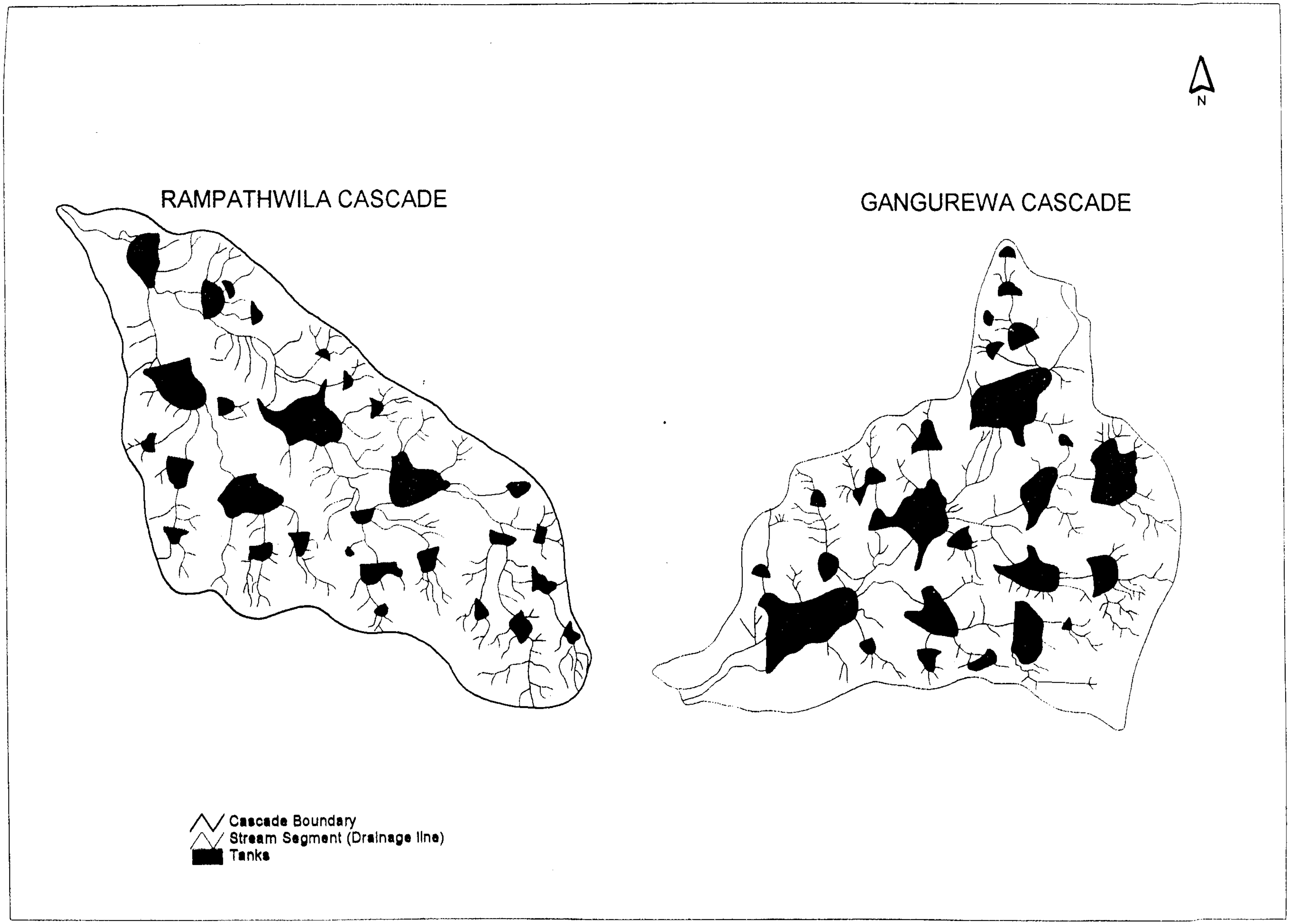

Cascade Boundary
Stream Segment (Drainage line)
Tanks
MANKULAMA CASCADE
N
ICHCHANKULAMA CASCADE
KAPIRIGGAMA CASCADE

Figure 4a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RAMPATHWILA CASCADE
GANGUREWA CASCADE
Cascade Boundary
Stream Segment (Drainage line)
Tanks

Figure 4b

It has been earlier established from quantitative studies that cascades which have a CAA/WA ratio higher than 8.0; and a COA/WA ratio less than 1.0, have the necessary hydrological potential for assured wet season rice cultivation.

A study of 230 cascades in 16 Divisional Secretariats in the Anuradhapura district shows the following results:

Number of Cascades with CAA/WA > 8.0	197
Number of Cascades with CAA/WA < 8.0	33

Number of Cascades with COA/WA < 1.0	40
Number of Cascades with COA/WA > 1.0	190

It could be seen from the above results that a high proportion of the 230 cascades of this district have an adequate catchment area where the CAA/WA ratio is higher than 8.0. On the other hand, it is quite clear from the above data that the command area of a very high proportion of these cascades is very much in excess of the tank water spread area, and these imposes a severe stress on the overall hydrological balance of the cascade. Because of the unrestricted expansion of the "akkarawela" extents that have taken place over the last 75 to 100 years, the tank wâter supply is not able to meet the normal irrigation requirements of the present command area. In the search for a reliable and easily measurable index for characterizing the **hydrological endowment** of a cascade, it was found that the **Cropping Intensity (CI)** of the small tanks located within the cascade, averaged over five consecutive maha seasons, provides a reliable and easily measurable integrated value of its hydrological endowment.

The range of values of Cropping Intensity (CI) in respect of 50 cascades in the Anuradhapura district is shown below in Table 2.

Table 2. Cropping Intensity of 50 Cascades in Anuradhapura District

Cropping Intensity*	No. of Cascades
> 9.0	5
8.0 - 9.0	8
7.0 - 8.0	12
6.0 - 7.0	13
5.0 - 6.0	8
< 5.0	4

* 9.0 denotes 90 percent
5.0 denotes 50 percent

As seen in the above Table, fifty percent of the cascades of the Anuradhapura district have a maha season cropping intensity of between 60 to 70 percent, while a further 25 percent have a maha season cropping intensity of less than 60 percent. This indicates the great variation in the hydrological endowment of cascades across this district. It is generally observed that the cascades in the western segment of this district have a lower CI than those in the eastern segment; and this is closely related to the amount of rainfall received during the usual maha seasons in these two segments. This has been well illustrated in Figure 3 of Panabokke's (1999) publication.

The Abandoned Tanks of the Rajarata, Ruhuna, Wayamba and Wanni

A total of six river basins that make up the Rajarata, and eight river basins that make up the dry zone part of the Ruhuna have been studied in detail. A further ten river basins of *the Wayamba or North Western Province (NWP), and ten river basins of the Wanni or* Northern Province (NP) were also studied in a more general manner for purposes of comparison. The percentage of functioning and abandoned tanks in each of the foregoing regions is shown below.

Region	Total No. of Small Tanks	Percentage Functioning Tanks	Percentage Abandoned Tanks
Rajarata (NCP)	4,017	52	48
Ruhuna (SP)	1,410	46	54
Wayamba (NWP)	6,463	65	35
Wanni (NP)	1,424	43	57

Adopting a heuristic approach, it could be demonstrated that there are different sets of reasons for the abandonment of small tanks in the different regions of the dry zone, especially in the Rajarata and the Ruhuna.

In the western aspects of the **Rajarata** the abandonment is primarily due to the poor soil and land quality, combined with a low hydrological endowment. In the eastern aspect it is primarily due to the sharper relief of the meso-land forms, and less to the land quality and nature of the hydrological endowment. The more stable small tank cascade systems are characterized by almost a total absence of abandoned tanks. These are found in the upper aspects of the sub-watersheds and have been discussed in a preceding section of this paper.

In the **Ruhuna**, the primary reason for the occurrence and preponderance of abandoned small tanks in the semi-arid environments is the sodic soil (solodized solonetz), in combination with a very low hydrological endowment. By contrast, the primary reason for the occurrence and preponderance of abandoned small tanks in the quasi-cascades of the Timbolketiya topo sheet, which is situated in a semi-humid environment, is the very

high runoff generated from the shallow and rocky land surfaces of the small tank catchment areas.

Differences in the macro- and meso-drainage patterns between the Rajarata and Ruhuna landscapes also have a close bearing on the nature and distribution patterns of small tank cascade systems in the two respective environments.

From any point of view, it could be argued that there had been adequate justification for the restoration of the abandoned ancient **major** irrigation reservoirs in the dry zone. The same rationale cannot however be extended to the restoration of the many abandoned **minor** small tanks in the same region. Selective criteria are now available for determining which of those types of abandoned small minor tanks would be worth restoring. These criteria have been discussed in Sakthivadivel *et al.* (1996).

In the final analysis, there is little or no rationale for restoring a greater majority of these abandoned small tanks; rather priority attention should be given to ensuring the productivity and sustainability of the presently functioning small tanks. By making use of the recently developed criteria it should be possible to rank the large number of presently abandoned small tanks according to their suitability for restoration, or else for restoration as water bodies exclusively for enhancing the groundwater regimes of these regions.

Sustainable Production Thresholds of Small Tank Systems

The Diversity of Production Systems within a Meso-catchment Basin and their Implications

Both traditionally, and even up to modern times, a diversity of production systems could be identified within a meso-catchment cascade basin. In order of importance these are (a) rainfed upland or "chena" cultivation, (b) lowland rice cultivation under small tank irrigation, (c) homestead mixed gardens, (d) cattle grazing and herding, and (e) food gathering from tank bed and similar sources and game harvesting from adjacent forest.

Traditionally it was a closed system within a tank village or a cascade, with the settlers living a frugal and contended life with very little external inputs. This situation has undergone radical change over the last 150 years, and the main production systems are now linked in many ways to external supplies and market forces. As a result, the earlier self sufficient subsistence equilibrium no longer prevails, and many imbalances are now recognized.

One of the major problems facing the transformation or the modernization of the traditional farming systems within a cascade is that of bringing about a balanced utilization of the present resource base in terms of the productivity of the different production systems in relation to the external market forces that now operate in the contemporary environment. This needs a careful analysis of the various factors of

production of the diverse agriculture and livestock production systems, and also a careful examination of how these interact with market forces outside the cascade area. It is only when these studies have progressed to some degree that it will be possible to pilot test the relevant interventions that have to be carried out with a view to modernizing the traditional farming systems.

Multiple Uses of Water within a Cascade

It is now becoming increasingly evident that the surface waters that have been captured and stored in these small village tanks had served a multitude of functions apart from irrigation supply for paddy during the wet maha season. It had been recognized by Ievers (1899), and Abeyratne (1956), that because of the highly variable nature of the rainfall coupled with the high evaporation rates for a greater part of the year and the paucity of readily accessible and adequate groundwater supplies in this hard rock region, it was these small tank surface storage systems that provided the lifeblood for human existence in this environment.

It is also now being increasingly recognized that the uses of water for several other essential purposes such as inland fisheries, livestock needs during the dry season, replenishment of groundwater conditions, domestic bathing needs and environmental amelioration during the enhanced dry moths from July-September, should all collectively be assigned an economic and social value.

It is also considered essential to partition the efficient use of the direct rain or the **green** water which is more efficiently utilized by rainfed "chena" cultivation, in contrast with the runoff collected and stored **blue** water in these small tanks which is less efficiently utilized in paddy cultivation as shown by Navaratne (1998).

Balancing and harmonizing the utilization of this green water and blue water components should undoubtedly be a major research and management thrust in the future research mandate of the Department of Agriculture. Sustainable food production within a cascade or meso-basin would, in the long run, be strongly governed by our ability to achieve a balanced use of both direct rainfall and surface stored supply of small tanks.

Balancing Production Thresholds with the Hydrological Endowment of Cascades

In the preceding section of this paper, the wide range in variation of the hydrological endowment of cascades was recognized. This was clearly reflected in the values of Cropping Intensity (CI) of irrigated rice across cascades which was observed to range from below 50 percent to more than 75 percent. It was also noted that the extent of the total catchment area of a cascade determined the amount of runoff that could be collected within the small tanks situated in the cascade; and that much of this catchment area was also subject to "chena" or rainfed agriculture during the maha season. Hence the total agricultural production thresholds, both rainfed and irrigated, of the small tank cascade system should be subject to a high order of variation dependent on several known factors.

Furthermore, the reliance on food security from both highland rainfed crops and lowland irrigated paddy will also be highly variable between cascades.

There is also the need to recognize the existence of different rainfall probability regimes across the western segment and the eastern segment of the Rajarata, and this too would impose variable threshold potential for food production across this region. Based on an empirical body of data now available, it is possible to broadly quantify the contribution made to rainfed food crops and irrigated paddy across the range of hydrological endowments of the cascades that are distributed across this landscape. This would, in the final analysis, help to characterize the production thresholds of the various cascades; and this in turn would then have to be evaluated against the economic benefits that would accrue to the varying income levels of families now living within these cascade regions.

Newly Emerging Dimensions of Agrowell Development

One of the very significant developments that has taken place at a very rapid pace in recent times has been the construction of agrowells under numerous small tank command areas. Each of these agrowells can irrigate between 0.5 to 1.0 acre of land by lift irrigation, and the growing of high value crops during the dry season has helped to raise farmer income.

It must, however, be clearly borne in mind that this shallow groundwater table that is being presently exploited by these agrowells is very limited in its quantity, and it is also of a very ephemeral nature. If it is over-exploited it could lead to very disastrous consequences both environmentally and economically. This shallow groundwater which is now termed the **regolith aquifer** is restricted to a definite landscape position within a cascade of small tanks, and is not ubiquitous as commonly perceived. The small tanks within the cascade also help to recharge and augment this shallow groundwater table during the rainy season, which in turn can be exploited during the dry yala season.

There are now well proven and reliable methods and guidelines available for estimating the location, spacing and density of agrowells in this regolith aquifer of the hard metamorphic rock basement region. These guidelines should be strictly enforced and adhered to in order to prevent serious ecological and environmental degradation taking place in this small tank cascade environment.

A recent study conducted on 50 cascades within the Anuradhapura district (Senaratne, 1996) has shown that the optimum number of agrowells that could be safely accommodated within these 50 cascades is not more than 3,600; and that already within five of these 50 cascades, the number of agrowells had already exceeded the upper critical limit. The red signal has therefore been already flashed, and time is now appropriate to take timely action to prevent any further expansion of agrowell construction in these stressed areas.

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