The Nature of Small-Scale Farmer managed Irrigation Systems In North West Province, Sri Lanka and Potential for Aquaculture.

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By
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Preface & Acknowledgements

These working papers are interim components of a UK Department for International Development (DFID) funded natural resources research program R7064, currently operational in Sri Lanka and Southern India. The project is of 3 years duration from 1999-2002 and aims to investigate the potential for integrated aquaculture options within small-scale farmer managed irrigation systems to bring benefits to marginal groups within diverse, risk-prone semi-arid and water-stressed regions of the world. Benefits are expected to be increased opportunities for livelihood diversification and more efficient and sustainable use of dwindling per capita water supplies.

Principle collaborators are the Institute of Aquaculture, Stirling University, UK, and in Sri Lanka the Agribusiness Centre of Peradeniya University and CARE international. The latter have also provided generous in-country financial support.

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All statements of fact or opinion in this document should be taken as interim statements. The work is continuing and matters covered in this report may be revised in the light of future information received. The document has been prepared to provide information exchange within the research team and with counterparts elsewhere. Comments or requests for further information are invited and should be sent to the project leaders in UK or Sri Lanka listed below:

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Project background

Arid and semi-arid regions of Southern India and the lowland Dry-zone of Sri Lanka's are representative of water-stressed areas experiencing erratic seasonal water availability, high rates of land degradation and chronic poverty. It is estimated that almost half the world's poorest people, nearly 500 million, live in such drought prone-areas and depend on irrigated agriculture to provide them with much of their food supply (UNDP 1997). This will rise to 20% of the world's population by 2050 (Engelman and Leroy 1993). Increasing frequency of drought and competition for water with industrial and domestic users will combine to make water a dwindling per capita resource in these areas. It has been predicted that both India and Sri Lanka will face a fresh-water crisis in the near future (Nigam et al, 1998). Much water is currently wasted due to inadequate management and conservation practices. World-wide irrigation efficiency[1] may be as low as 37% (Postel 1996) and there is a need for more integrated approaches to water management which take into account its multiple uses for purposes besides irrigation (Gowing 1998, Redding 1990). Since agriculture is responsible for some 70% of global water use (FAO 1995), the potential for water savings through multiple use, including aquatic production is enormous.

An emerging development priority has emerged following a paradigm shift where irrigation systems are being reassessed as components of the whole water basin. It is now realized that water and land management practices at the wider watershed level can lead to increased options for on-farm water management at the individual level (Pretty 1995). Watershed development is a huge development initiative in Sub-Saharan Africa, India and other semi-arid areas of the world and often involves the construction of large numbers of small community or farmer-managed water bodies for rainfall harvesting, groundwater recharge and the prevention of soil erosion. In Sri Lanka, as in many parts of India, traditional watershed management exists in the form of the ancient community-managed cascade tank systems. Large-scale rehabilitation of tank systems has taken place over recent decades in both countries.

Two thirds of the predicted shortfall in world fish production (20-30 million tonnes by the year 2000) will occur in the semi-arid tropics (FAO 1995), further underlining the need for such research effort. Despite this potential, attempts to integrate fish production into these water bodies have been rare and usually based on conventional commercial semi-intensive pond aquaculture. Whilst the resource-rich have been able to adopt such an approach, it has proved inappropriate for poorer marginalised groups. By investigating aquaculture options for both traditional and modern watershed development structures, the research results are likely to have broad applicability.

Although large-scale irrigation systems supply the greatest area of farmland, the greatest numbers of farmers still cultivate in rain-fed dry lands, where they rely on small-scale systems. Furthermore the scope for further expansion of large-scale systems is limited, whilst great potential exists to increase the availability of smaller systems through the adoption of watershed development programmes, which include water-harvesting components.

The project aims are to identify social and bio-economic constraints to the integration of aquaculture into farmer-managed irrigation systems and to develop and promote effective approaches to aquaculture for farmers in diverse risk prone dry-land regions of India and Sri Lanka. Intended beneficiaries are the rural poor. Within this group, opportunities for landless, lower caste unemployed youth and women's groups, all of whom have traditionally derived least, benefit from irrigation developments, will be given special consideration. The project has sought to promote a participatory approach to the design and implementation of targeted research. Research outputs include technical guidelines to engineers, policy guidelines to

[1] The percentage of irrigation water actually consumed by crops during their growth.

planners and donors, research guidelines to scientists and extension guidelines to field-level implementers. The closely linked DFID KAR[2] engineering programme (R7123) is investigating the potential for integrating aquaculture into larger formally managed irrigation systems of semi-arid areas in contiguous research areas.

This series of working papers is based on field research that took place during December and January 1998. The social, economic and technical feasibility of fish production in such systems were investigated and some preliminary constraints to the uptake of poverty focused aquaculture identified. Research included a 'Rapid Rural Appraisal' of two cascade systems in Puttalam and Kurunegala districts (incorporating a total of 21 tanks and 9 villages), and semi-structured interviews with representatives of Government fisheries departments, fisherman's co-operatives, marketing agents and other relevant institutional organisations throughout the country.

Field work was undertaken in collaboration with the, field staff of the NGO's CARE[3] IFAD[4] the Government '*Samurdhi*' welfare programme and the Agricultural Economics department and Agribusiness Centre (AbC) of Peradeniya University.

List of working papers in the series:

SL1.1 The Lowland Dry Zone of Sri Lanka; Site for Study of Aquaculture Development within Farmer-managed Irrigation Systems and Methodology for Participatory Situation Appraisal.

SL1.2 Inland Fisheries Resources and The Current Status of Aquaculture in Sri Lanka and North West Province.

SL1.3 The Nature of Small-Scale Farmer Managed Water Resources in North West Province, Sri Lanka and Their Potential for Aquaculture.

SL1.4 Fisheries Marketing Systems and Consumer Preferences in Regional and Sub-Regional Markets of Sri-Lanka.

[2] Knowledge And Research
[3] Caring About Relief Everywhere
[4] International Fund for Agricultural Development

Glossary

AER	Agro Ecological Region
ADB	Asian Development Bank
Anicut	A perennial stream diversion used for irrigation.
CARE	Co-operative Assistance Relief for Everyone (US NGO)
CBNRM	Community Based Natural Resource Management
Chenna	Fixed or shifting dry-land cultivation
CMA	Conflict Management Assessment
CPR	Common Property Resource
DAS	Department of Agrarian Services
DDS	Death Donation Society
DDW	Danduwellawe (primary research village)
DS	Divisional Secretariat (lower government administrative division)
DFID	Department For International Development (formally ODA)
FO	Farmers Organisation
IFAD	International Fund for Agricultural Development
LHG	Low Humic Gley
LDZ	Low-Land Dry Zone
LGP	Length of growing period
GN	Grama Nilhadari (village-level Govt. Admin. Officer)
GSN	Govi Sevena Nyamake (village-level farmer extension officer).
GoSL	Government of Sri Lanka
Ha	Hectare (= 2.4 acres)
Maha	Major cultivation season (associated with NW monsoon)
NCP	North Central Province
NERS	Non-Equilibrium Resource Systems
NGO	Non Governmental Organisation
NWP	North West Province
OFCs	Other Field Crops
PC	Purana Complex (or Cluster)
PDW	Pahala Diulwewa (primary research village)
PET	Potential Evapo-Transpiration
PRA	Participatory Rural Appraisal
RRA	Rapid Rural Analysis
RBE	Reddish Brown Earth
RRA	Rapid Rural Appraisal
Rs	Rupees (Sri Lankan unit of currency; $1 = Rs 65)
Samurdhi	Government welfare program
SAT	Semi Arid Tropics
STC	Small Tank Cascade System
UNDP	United Nations Development Program
Velvidane	Traditional irrigation headman
Wewas	Tank
Yala	Minor cultivation season (associated with SW monsoon)

Executive summary

This paper aims to characterise the nature of small-scale farmer managed irrigation systems in the dry lowland agro-ecological zone of Sri Lanka and to identify the researchable constraints to uptake of sustainable aquaculture options relevant to the poor. Based on analysis of secondary and primary data, researchable constraints are identified throughout the text and aquaculture potential in different sub-components of the irrigation system assessed.

RRAs were carried out in two Small Tank Cascade systems (STCs) of North West Province, Sri Lanka (less than 1000 ha total watershed area). A total of 21 tanks and 7 villages were investigated with primary emphasis on two upper watershed communities. The two systems differ primarily in their resource base; namely rainfall, natural forests and proximity to large-scale perennial irrigation resources.

Though large in number, most reservoirs in Sri Lanka are relatively small and shallow in comparison to the rest of Asia and have realised high potential for fish production since the introduction of exotic tilapias in the 1950's. Village life in the Lowland Dry zones has evolved around the irrigation of paddy using rainwater stored in small-scale seasonal reservoirs (known as tanks). These tanks are clustered within watersheds into STCs consisting of 2-25 tanks mostly between 4 – 50ha in extent. Slightly over 18,000 tanks have been surveyed, less than half of which are currently supporting village communities. These tanks are located through out the Lowland Dry Zone with greatest concentrations in the research area of North West Province and Anuradhapura districts.

In the 1950's, these resources were effectively nationalised by the state, ending a tradition of community ownership, operation and maintenance. Limited government capacity, economic and demographic changes and the weakening of village-based institutions, have lead to a progressive deterioration in the management of these resources. Extensive bilateral tank rehabilitation programs designed to address these problems were initiated in the 1980's, but few have been successful in achieving both good physical results and farmer mobilisation.

With few exceptions, these schemes operated at the level of the individual tank. Today poor awareness of the need for integrated development at the watershed level continues to be a major constraint to sustainable development. Whilst rehabilitation can increase the storage capacity of individual tanks, interventions undertaken without a basic understanding of cascade hydrology can result a variety of negative effects, including water deficits simply being moving down stream or impeding the natural recruitment of migratory fish stocks. A simple model proposed by Sakthivadivel (1997) is used to estimate the deficit or surplus water status of the cascade systems and conclusions are drawn for sustainable low input enhanced fisheries options, identified as being most suited to local farmer needs and resource usage priorities. Danduwellawe cascade was identified as a deficit system, whilst Pahala Diulwewa is a surplus cascade where irrigation and aquaculture potential could be enhanced by increasing tank capacity.

In mid-to upper watershed areas we define the basic unit of settlement as the '*Purana Complex*' (PC). These traditional assemblages comprise discrete communities linked by systems of caste and kinship, sharing access to a range of village institutions and common property resources including tanks. Within PC boundaries, settlement is normally concentrated around a larger axial tank whilst younger; resource poorer farmers are forced to settle around smaller and more seasonal radial tanks. Ownership of irrigated lands under these tanks resides with the longer established community around the axial tank.

Disparities exist between as well as within, PCs. Generally cultivation potentials are lowest within upper watershed PCs where often only supplementary irrigation is possible due to the progressively more seasonal nature of water availability. This problem is compounded by the

incursion of marauding wild animals at the top of Danduwellawe cascade. Social barriers imposed by caste reduce potential for co-operation between neighbouring PCs. External facilitation is therefore required to encourage integrated watershed development. Existing village-based officers of various government line agencies offer good potential to build upon in this respect.

No effectual fisherman's organisations were found in any of the PCs and most fisheries are effectively open with much of the harvesting effort takes place on a collective basis at the end of the dry season. In ranking exercises where villagers' valued water in village tanks for different uses, fishing was consistently given low priority, largely due to the high availability of low cost, higher quality tilapia from artisanal fisheries in nearby perennial reservoirs. In upper watershed areas farmers valued bathing almost as highly as the primary use of water for irrigation, reflecting a trend of decreasing agricultural yields under seasonal tanks and an increasing reliance on off-farm labour. These groups, often of low caste status, were also likely to have the greatest relative reliance on exploitation of the natural resource base for subsistence purposes. This includes the exploitation of fisheries in less seasonal tanks in a wide radius out with their own PCs. Younger males who fish mainly for recreational purposes are the most important group of people exploiting the fisheries resource currently. Such activity is generally tolerated at low levels, particularly when seasonal fishing bans imposed to preserve water quality for the priority use of bathing are not openly broken.

Traditional individual tank-based stocking interventions which favour larger semi-seasonal or perennial village tanks have often failed in large part, due conflicts arising from the exclusion of these existing user groups, who are labeled as 'poachers' and 'part of the problem'. Consequently, upper watershed PCs are identified as key sites for future research. The equitable distribution of benefits to such groups through improved management and biomass production in CPRs is recognised as a key requirement for sustainable watershed development. In addition to the relative poverty of these PCs, the smaller size of upper watershed communities reduces the complexity associated with their management. With respect to fisheries development the greatest challenge lies with the mismatch between the existing reliance of these groups on capture fisheries and their lack of assured access to suitable water bodies.

Farmers perceived erratic water availability, predation and in one lower watershed village, poaching, as the greatest constraints to the adoption of stocking and management of tanks. However in the absence of hatchery-produced seed, and where a need exists to optimise catch per unit effort before yield, future work should focus on identifying extensive means to enhance production using locally available wild seed. These may be fingerlings available during spill events, or *in-situ* production using broodstock sourced from perennial waters. Some farmers around more seasonal tanks were identified as already undertaking such practices, albeit at low frequency. Further research should also investigate the effects of different rules and access restrictions imposed by community based organisations, on equitable and sustainable fisheries management.

Other potential constraints to aquaculture identified during the study included:

- Accumulation of pesticide residues within STCs.
- Aquatic weed encroachment, leading to loss of tank capacity and primary productivity
- Transmission of fish diseases (Epizootic Ulcerative Syndrome).
- High natural predation levels.
- Restrictions to natural migration of fish through watersheds following tank rehabilitation.
- Catchment degradation and tank siltation

The importance of these factors appears to vary with position in the watershed, further underlining the need for a watershed approach.

Table of contents

List of figures

List of tables

List of boxes.

PART I

Small-scale farmer managed irrigation systems in Sri Lanka

1 Introduction

Sri Lanka is richly endowed with fresh water resources, with an estimated 3ha of water for every km^2 of island. This predominantly man-made resource has made extensive settlement in the Lowland Dry Zone possible through the practice of irrigated agriculture. Today Sri Lanka has more than 18,000 functioning irrigation schemes covering some 600,000 hectares at full capacity. About 90% of this number are classed as minor irrigation schemes (see Box 1) irrigating some 150,000 hectares (IMMI 1998). These small-scale farmer-managed systems are a vital resource in securing the livelihoods of some of the poorest communities in the country. With respect to these resources, this paper deals with the following research objectives:

- To characterise the nature of small-scale farmer managed irrigation systems (and ancillary water bodies) in dry lowland agro-ecological zones of Sri Lanka.
- To identify researchable constraints to uptake of sustainable aquaculture options relevant to the poor within these resources.

Secondary data is presented in Part 1 (sections 1- 8), whilst outputs from Rapid Rural Appraisals (RRAs) in two Small Tank Cascade-systems (STCs) are presented in Part II (sections 9 – 18).

2 The research area

Two cascade systems in Puttalam and Kurunegala Districts were selected as sites for RRA based on a screening of 14 cascades systems in Central, North Central, and North West Provinces (see Working Paper SL1.1). These areas are representative of a wider agro-ecological region known as the Lowland Dry Zone, which experiences high levels of rural poverty associated with short rainfed growing seasons and degrading, nutrient-poor red soils. North Central and North Western Provinces are the two Provinces in Sri Lanka most richly endowed with small-scale tank systems. Danduwellawe[5] (DDW) cascade lies within the Galgamuwa Divisional Secretariat (DS[6]) in Kurunegala District, whilst Pahala Diulwewa (PDW) Cascade lies some 40km to the Southwest in the Anamaduwa DS of Puttalam District.

The NGOs IFAD and CARE facilitated community access in DDW and PDW systems respectively. Both organisations are implementing integrated rural development programs incorporating tank rehabilitation components in a number of villages in each system. Entry into the Danduwellawe system was also facilitated by staff of the Government poverty alleviation program; Samurdhi. Figure 1 shows the location of the study areas within North West Province. Schematic representations of the cascade systems are shown in Figs. 5 and 6.

With respect to livelihood potentials, the two research areas were distinguished by three broad differences in their natural resource base:

- *Rainfall:* Mean annual rainfall levels were higher and less erratic in the PWD area (see Working paper SL1.1) and this became highly evident in the hydrological assessments of the two systems (see section 10).
- *Irrigation resources:* Although both areas benefit from extensive developments in major and minor irrigation schemes with assured water supplies, fewer of these resources exists in the immediate vicinity of DDW (see Fig 1.). Farmers here have

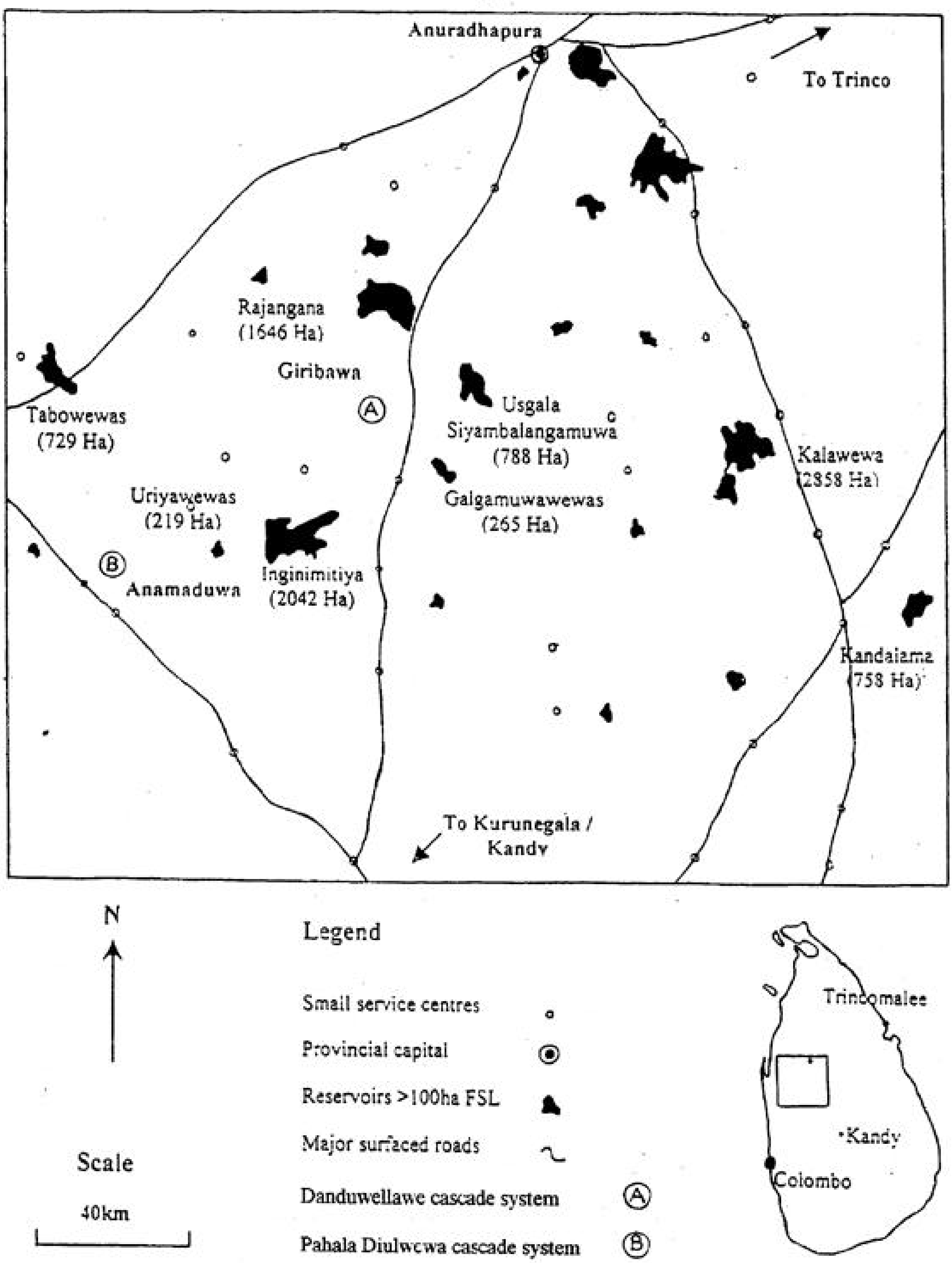
[5] For the purposes of this report the cascade systems will be named after the primary village investigated (it is the convention normally to name the cascade after the largest tank).

[6] Divisional secretariats represent the lowest administrative division normally incorporating 1-6 villages.

fewer opportunities to leasehold or sharecrop land under perennial systems and consequently have greater dependence on their immediate resource base (see section14).

- *Natural forest resources:* In the immediate vicinity of PWD system, these resources had been cleared, and replaced with fixed upland cultivation, scrub forest, or teak and eucalyptus plantations. In the remoter DDW area extensive areas of natural forest still remain, bringing both livelihood opportunities (slash & burn cultivation, foraging, logging, hunting etc) and conflicts (marauding wild animals, catchment degradation etc).

Fig 1: Location of research areas in North Western Province (A and B)



3 Methodology

Rapid Rural Appraisals focused on the key villages of Danduwellawe (DDW) and Pahala Diulwewa (PDW). The major uses of water bodies as well as the key constraints to the introduction of aquaculture into village tanks were identified in community meetings and ranked and scored in order of priority by farmers. To assess the wider impacts of water and land management practices, appraisal was extended to the cascade level using individual farm and catchment walks and key informant interviews. Farmers were questioned about historic trends in water availability, tank system operation, maintenance and management. A total of 82 farmers were interviewed during this process (33 and 49 in DDW and PDW respectively). Basic water quality parameters (pH, conductivity, turbidity and temperature) of different water bodies at different levels of the watershed were measured *in-situ*. Maps of the cascade systems were constructed with farmers during community meeting[7] and triangulated by reference to 1:500,000 survey maps (see Appendices 8 and 9) and cascade transect walks. Results of the RRA were used to assess the hydrological endowment of the cascade systems according to a model evolved by Sakthivadivel (1996, 1997). The resulting index is valuable in assessing aquaculture potential, in addition to being a relative indicator of poverty at the cascade level.

4 The historic development of Sri Lanka's irrigation systems

Sri Lanka has a proud history of irrigation development with a hydraulic civilisation dating back over 2,000 years. Irrigation developed for the primary purpose of rice cultivation, as rice is the nations staple food along with fish. With the exception of several coastal sites, most early settlements developed in the inland areas of the dry zone hinterland based on agricultural activities focused around small-scale irrigation tanks. This brought into being a society based on a so-called 'one tank, one village' system. Most of these village irrigation works were collectively owned and constructed using communal labour.

From the first century AD irrigation development came increasingly to be undertaken as a large-scale state level enterprise. Bigger reservoirs were built, existing ones expanded and channels and anicuts[8] were used to develop complex feeder systems. Development of two dry-zone complexes of irrigation works, one around the Maluatu Oya and the Kolu Oya and the other based on the Mahaweli River system and it's tributaries continued into the 12th century. These systems along with small village tanks spread over much of the dry zone and provided a foundation for the civilization, which flourished in the period from the 4th to the 13th century AD. In the hill country wet zone, simple anicuts were used for paddy cultivation (Somasiri 1986).

At the end of this period the great dry-zone cities of Anuradhapura and Polonnaruwa had been abandoned. This was attributed to an increase in internal and external wars and an epidemic of unknown aetiology, probably malaria. By the end of the 15th century only the ruins of the once flourishing 'hydraulic' civilisation remained. The population began to move to the wetter highland areas where smaller kingdoms prospered independently until the whole island came under British rule in the early 19th century.

During the following centuries which encompassed the Portuguese, Dutch and early British colonial periods, the interior of the dry zone lay desolate and sparsely populated. The remaining villages, surrounded by jungle were still grouped around small irrigation tanks. The economic life of such villagers revolved around paddy and *chenna* (rainfed slash and burn) cultivation and subsidiary occupations including fisheries (Siriweera 1986).

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[7] Also included were the location of ancillary water resources including agro-wells and tube wells

[8] Diversions from perennial streams.

The British Colonial Government enacted their first Irrigation Ordinance in 1856. This was an attempt to re-introduce the ancient system of village committees (*Gamsabhawas*) that enforced the customary rules in relation to the construction and maintenance of irrigation structures and the distribution of water. The success of this system in meeting the policy objectives of the colonial administration, lead the government to extend their functions, including other matters related to cultivation and fisheries. The re-introduction and extension of these functions are seen as the launching pad of modern local government in Sri Lanka (Wanasinghe 99).

Re-colonisation of the dry zone began in earnest in 1931, when the Colonial Government recognised that systematic restoration of the ancient irrigation works was essential to support the growing needs of the plantation sector and general economic growth of the island. After independence in 1948, re-colonisation took place in earnest to relieve increasing population pressure in the hill country. A large new multipurpose project, the Gal Oya scheme was completed in the 1950's, whilst the largest program, the Mahaweli Project was launched in the 1960's (see Working Paper SL1.1). These programs and the large-scale resettlement that accompanied them brought many new social and environmental problems, but contributed to the wider food security and social stability of the island. The often-heterogeneous composition of resettled communities around these communities stands in contrast to the more traditional communities around small-scale systems where colonisation of recently rehabilitated tanks tends to occur on a much more local scale (see section 14).

5 Classification of large and small-scale irrigation systems

Irrigation systems can be classified according to various criteria including:

- Area or volume of the storage tank,
- Command area or the number of crops that can be irrigated,
- Primary function (i.e. irrigation, flood control, electricity generation),
- The system of management, or the nature of the source of water (i.e. canal diversion, ground water or rainfed).

Box 1. Administrative classification of irrigation systems in Sri Lanka, based on size of command area.

Classification	Size (ha)
Major	>600
Medium	80-600
Minor	<80

Source: DAS (1999).

For administrative purposes irrigation reservoirs in Sri Lanka are classified according to the size of their command area as indicated in Box 1. Medium and Major systems are the responsibility of the Irrigation Department, whilst Minor tanks come under the jurisdiction of the Department of Agrarian Services (DAS). Only the smallest tanks (<5-10ha) are privately owned and managed.

With respect to poverty-focussed potential for aquaculture, a more functional distinction lies in the greater ability of farmers and communities around smaller systems to manage their own water resources with negligible intervention from external institutions. In Sri Lanka the Irrigation Department undertakes operation of major and medium systems with limited participation of farmer organisations. However, the distinction between small and large-scale systems according to this criterion has become less clear-cut with the recent appropriation responsibility for minor irrigation by a second governmental department; the Department of Agrarian Services (DAS). Day-to-day management operations, together with limited maintenance activities are delegated to farmer's organisations by the DAS, who in retain responsible for major maintenance operations. This has had negative impacts on water management as farmer's traditional sense of ownership has become eroded and communities increasingly dependent on external institutions. A second key distinction in our definition lies with the seasonal availability of water. Small-scale irrigation systems are 'non-system', that is their supply is not augmented with assured water supplies, or trans-basin diversions from larger rivers or reservoirs. Instead they are rainfed, directly harvesting rainfall and capturing runoff from ephemeral streams within their own catchments. They are often highly seasonal in nature. Most of the minor irrigation systems in the dry zone conform to this definition. Other small-scale micro-irrigation systems such as agro-wells rely on ground water extraction (see section 8).

Today much of the land and water resources in the 103 river basins of Sri Lanka have been harnessed, particularly for irrigation in the dry zone and little scope exists for further large-scale developments (Wijesuriya 1997). Increasingly, emphasis has been placed on the rehabilitation of minor irrigation resources (see Section 11 and Appendix 3), alongside attempts to improve water use efficiency in both large and small systems

6 The nature of small-scale irrigation systems

The importance of water resource management at the scale of the cascade or watershed level will be developed after considering some of the main characteristics of the individual tank.

6.1 Village tanks

Tanks are created by the construction of earthen dams across seasonal streams. Maximum water spread typically ranges from 4-50ha, whilst 80% are 25ha or less (see Table 1), whilst the average village tank is estimated to have an irrigable area of 42ha (Land Commissions Report 1985). Rainfall, although relatively high (>1,000mm/year), is highly variable (see Working Paper SL1.1) and soils are generally shallow and porous. Many tanks fill only in above average rainfall years. They receive most water during the Northeast Monsoon (Oct – Jan) and irrigate some 20-30ha during the subsequent main *maha* cultivation season (Oct-Mar). Water levels recede gradually from Feb-Mar onwards, but may fluctuate due to intermittent rains during the SW monsoon (Apr-Jun), evaporation and occasional drawdown for agricultural purposes during the secondary *yala* cultivation season (Apr-Jul). Many smaller tanks in upper watersheds retain water for only 6-7 months of the year, and this highly seasonal and erratic water availability means that often only supplementary irrigation[9] is possible. Tanks are often pumped below dead storage[10] for emergency irrigation, which has implications for the maintenance of stocks of fish and other aquatic organisms. Each small tank has it's own immediate catchment area but may also receive irrigation drainage water returns and over-spill from tanks higher in the meso-catchment. Therefore assessment of seasonal water storage potential requires an understanding of hydrology and farmer land and water management practices at the wider cascade level.

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[9] Where crop requirements are satisfied using a combination of stored water and direct rainfall, but not on either source alone.
[10] Water stored below the sluice level of the tank which is not available for irrigation purposes through conventional gravity supply.

Figure 2: General layout of a village tank (after Ulluwishewa 1991)

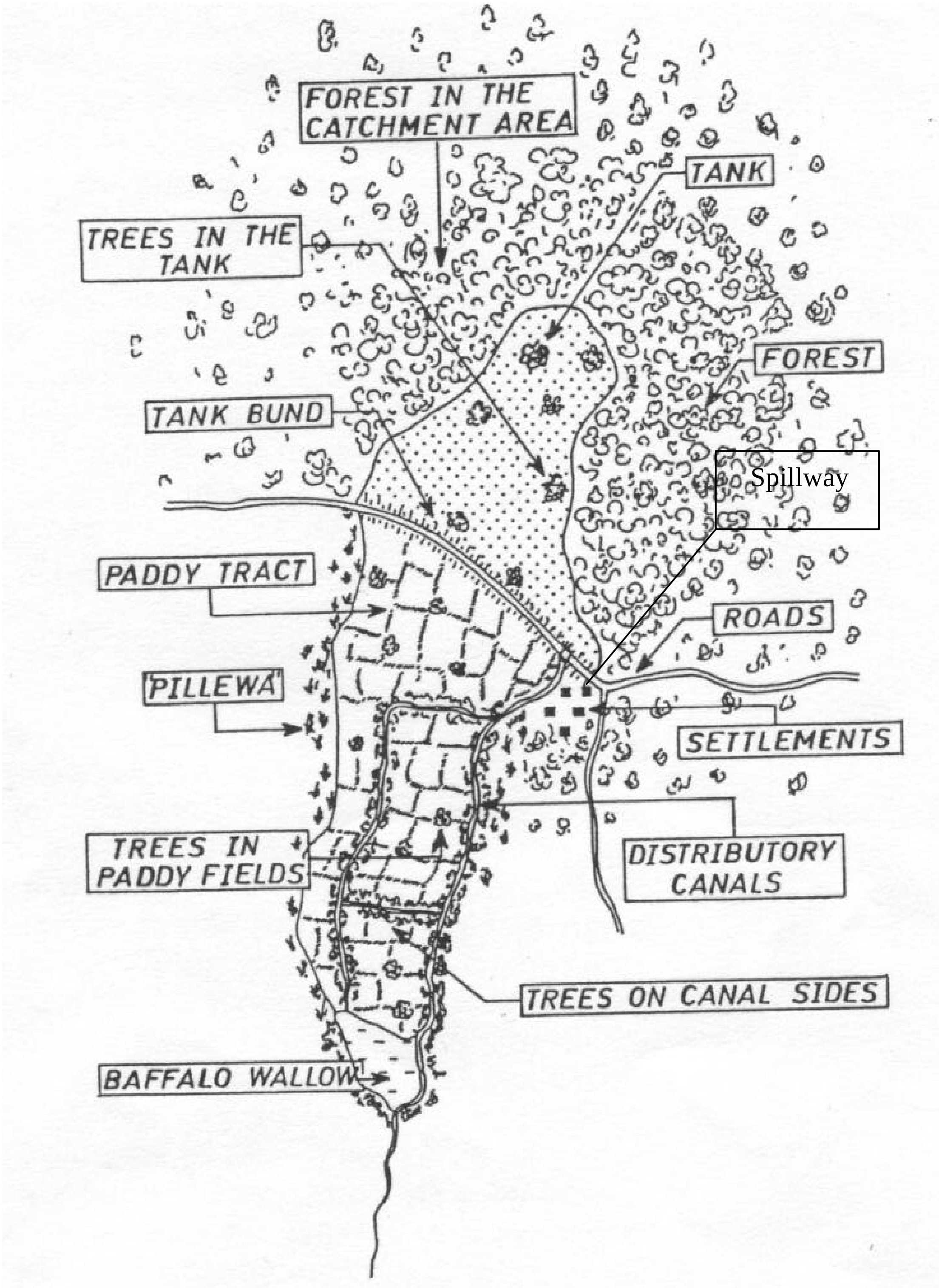


Figure 3. Schematic diagram of a Small Tank Cascade system. Scale 1:50,000 (Source: Sakthivadivel 1996).

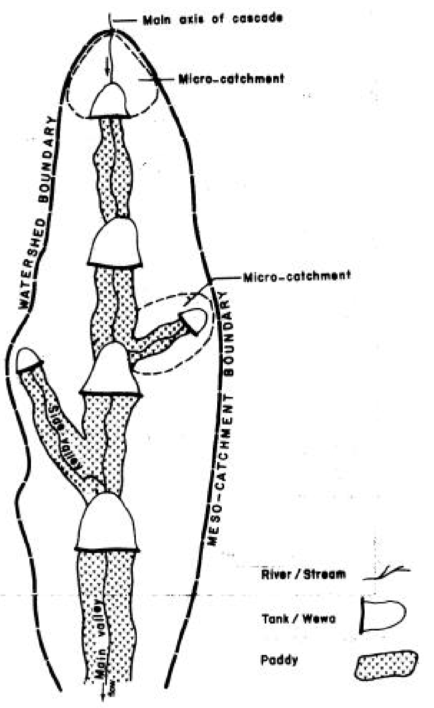


Figure 2 shows the general layout of a village tank. Water is used mainly for paddy irrigation during the *maha* season whilst a range of other field crops (OFCs), are occasionally grown during the *yala* season depending on water availability. Shifting or fixed upland cultivation, home gardening and fisheries are also important components of farming systems. Other secondary uses of the tank water include bathing, livestock[11] and domestic purposes. Historic evidence shows an awareness of the need for good watershed management. Watersheds were divided into different sections identified for specific purposes. People had their houses and home gardens close to the tanks, land adjoining the village was used for slash and burn (*chenna*) cultivation, whilst forests in the catchment above the village tank were left relatively undisturbed to minimise soil erosion and associated tank siltation. Traditionally, a pool receiving drainage waters was maintained at the lowest point of the paddy tract for use as a buffalo wallow. This was often a permanent body of water and acted as a refuge for fish, which re-colonised other parts of the system during the rains (Ulluwishewa 1994). The number of such wallows has declined as they are increasingly drained and put into agricultural production. This is associated with a trend of increasing farm mechanisation and concomitant decline of draught livestock ownership. Increasing pressure on land and water resources has also contributed to the accelerated breakdown of traditional catchment management practices. Many villages have access to one or more axial and a larger number of smaller radial tanks (see Fig 3.). A close association of kinship, land tenure and irrigation practice traditionally provided the basis for community management of these assets (see section 13).

6.2 Small-scale cascade systems

In the Wet Zone village tanks are supplied by perennial stream diversions (anicuts) whilst in the dry zone they are typically rainfed via ephemeral streams and clustered into Small Tank Cascades systems (STCs). An STC (see Figure 3) can be defined as a series of hydraulically connected small tanks within a *meso*-catchment[12] draining to a common reference point thereby defining a sub-watershed unit with a definite watershed boundary (Abernethy 1993). The system stores conveys and utilises water from first or second order ephemeral streams. (Bandara 1985). A cluster of cascades would in turn form a sub-basin of a river and a cluster of sub-basins the entire watershed of the river. Cascades systems range from 2-25 tanks (IIMI 1998) arranged in linear or radial patterns, with tank size generally increasing with progression down the watershed.

[11] Livestock holdings are generally low in the context of a predominantly Buddhist Society and poor resource base for ruminants.
[12] Sakthivadivel (1996) recommends the use of the term meso-catchment to represent the total watershed area of the cascade of tanks and the term micro-catchment to describe the immediate catchment of each individual tank within the cascade. This nomenclature will be adopted throughout this report.

6.3 The distribution of small-scale farmer managed irrigation systems.

From the third century BC to the 12th century AD many thousands of small village tanks were constructed in the island for the purpose of irrigation, drainage and flood control. An estimated 18,000 tanks are clustered into 3,500 to 4,000 STCs with greatest concentrations in the selected project areas of the North West and North Central Provinces covering some 24,000 $km^{2,}$ slightly over one third of the island surface area. Sakthivadivel (1996) identifies three principle factors governing the distribution patterns and densities of STC systems:

- *Rainfall distribution & amount:* Density decreases with increasing rainfall
- *Nature of the underlying geology:* Soil permeability (typically lowest in upper watersheds), impacts on tank size, distribution and seasonality.
- *Geomorphology:* Density is greatest in the 'gently undulating' areas (2-4% slope range) due to the greater retentiveness of the water table and lowest in the 'undulating' areas (4-8% slope range).

The combined effect of these factors results in the greatest concentrations of tanks occurring in upper reaches of third or fourth order watersheds of the dry zone[13]. In other words most STCs are concentrated around the larger rivers and their tributaries. In Anuradhapura District (the largest District in Sri Lanka) a comparatively high density is found over a central belt of Precambrian rocks, which give rise to a more compact and impermeable soil catena than in the SW of the district (see Fig 4).

Estimates of the number of small-scale tanks in Sri Lanka vary widely between different sources and generally give no indication of the operational condition of these tanks. The DAS, who have the primary responsibility for tank rehabilitation, disaggregate the distribution of tanks within the major districts of the dry zone, by size and rehabilitation status (See Table 1). The total number of operational tanks[14], is estimated at 9,147 irrigating a total of 148,589 ha, whilst nearly 76 percent of all tanks require further rehabilitation. Most tanks support some degree of irrigation, even those that require rehabilitation. Smaller tanks tend to be in the worst condition as cost-effective rehabilitation currently focuses on larger tanks supporting sizable communities (> 25 households). Rehabilitation has been uneven in the dry-zone. Puttalam District has one of the highest concentrations of tanks and has also benefited from a relatively high level of rehabilitation investment (see section 6.4 and Appendix 3).

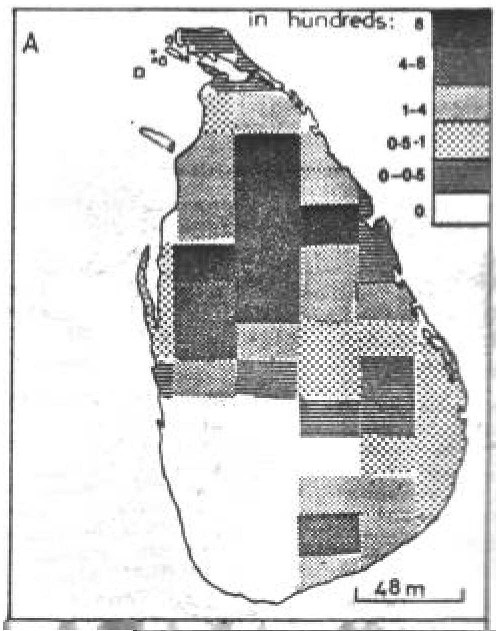
Table 1. Dry Zone minor irrigation tanks with less than 80 ha command area by District (Source: Department of Agricultural Services 1996).

Province.	District	Command area (ha)						Total (ha)	% Un-rehab[2]	Command Area (ha)	No. of Farmer Hseholds[3]
		0-5	5-10	10-25	25-50	50-100	>100				
N.C	A'pura	44	157	747	826	466	241	2,481	82	99,950	53,600
	Polo'wa	0	8	25	42	30	15	120	74	6,215	2,850
N.W	Putallam	123	131	237	184	51	26	752	56	21,000	16,400
	Kuru'la	1203	1037	1300	654	203	45	4,442	81	73,850	85,400
Uva	Dabulla	10	15	37	7	8	1	78	86	515	1,150
	Mon'gala	13	24	79	51	34	23	224	72	9,150	5,900
South	H'tota	35	73	146	206	54	19	533	48	11,100	8,100
Central	Matale	8	39	114	83	36	10	290	43	9,200	9,147
Total		1436	1484	2862	2053	832	480	8920	75.6	230,980	230,980

[1] Anuradhapura, Polonaruwa, Kurunegala, Dambulla, Monoragala, Hambantota.
[2] Percentage of un-rehabilitated tanks; requiring > Rs 2,500 per ha command area rehabilitation cost.
[3] Number of farmer households dependent on these resources

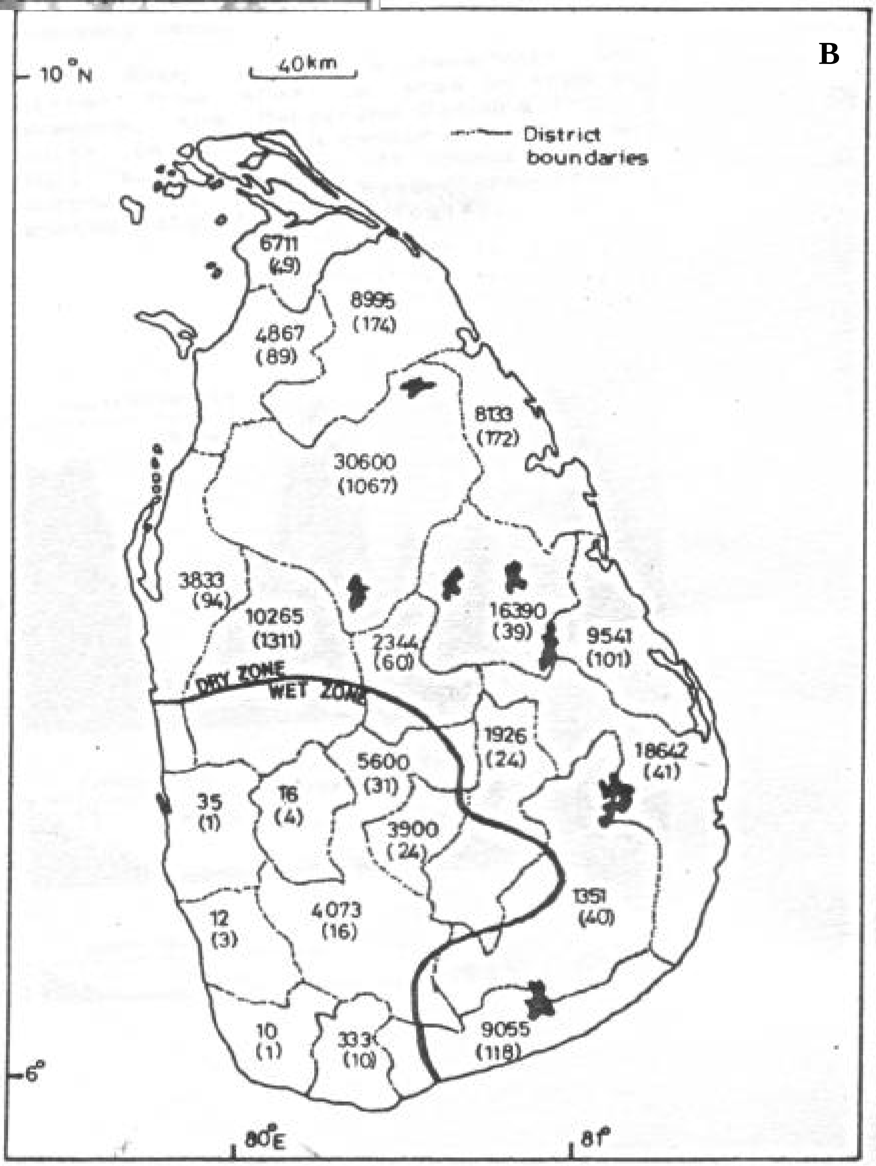
[13] Most of the larger dry zone rivers which drain directly to the sea are fourth order
[14] Tanks <80 ha command area which regularly irrigate paddy and support a local village or community.

Figure 4: The distribution of small-scale irrigation systems in Sri Lanka.



4A. Distribution of seasonal tanks (Source: Cook 1931).

4B. Reservoir surface area (ha) and the total No. in each administrative District. (Source: Fernando and De Silva 1984).



Tanks appearing on the one-inch topographical maps of the survey department maps have been numbered serially within each river basin. According to this system the total number of minor tanks in the country is 18,378 (both restored and abandoned). Wijetunga (1986) reports that many abandoned tanks have escaped topographical survey because they are still covered in scrub jungle or are otherwise inaccessible. He estimates that inclusive of these tanks, the total number is around 30,000, of which approximately 7,000 are still working and supporting village communities. In our own study, 3 of the 8 tanks located in the Danduwellawe cascade and 5 of the 16 in the Uriawewa and Pahala Diulwewa cascades, i.e. 33% of all tanks, were not marked on the most recent 1:50,000 1985 GoSL survey maps (see section 9). Whilst two of the larger unmarked tanks had recently been rehabilitated, the others consisted of smaller, more neglected and highly seasonal tanks.

6.4 Rehabilitation of small-scale irrigation systems.

Because of the importance of irrigation to livelihoods in Sri Lanka, improving irrigation facilities has long been a key component of rural development programs. State intervention began under British rule in the 1930's, focused on rehabilitation of major irrigation systems associated with the plantation sector with a view to providing sufficient locally grown food for the growing workforce. Only in the late 1950's did emphasis shift towards minor irrigation systems, with efforts intensifying from the early 1970's under both state and NGO intervention.

The term rehabilitation, as used in Sri Lanka, connotes at least one of the actions listed in Box 2. Early rehabilitation attempts were confined mainly to actions (a) and (b). After 1972, attention shifted towards actions (c) and (d) which proved a more cost effective use of limited funds. Prior to 1980 the primary aim of rehabilitation was to increase agricultural productivity, by increasing the cropped area and intensity of paddy cultivation. Interventions consisted of a combination of structural repairs and development of improved water management systems. Subsequently emphasis shifted to integrated packages with recognition that linkages between secondary livelihood activities and the primary activity of irrigated agriculture must be addressed in a holistic way to achieve sustainable development. These programs aimed to help farmers diversify their livelihood options and ensure more equitable benefits to those without reliable access to irrigated land.

Box2: Categorisation of tank rehabilitation strategies employed in Sri Lanka (IIMI 1996).

a) Restoration of an old *abandoned* tank, together with the command area under it.
b) Restoration of a '*non-working'* old tank where the bund is breached and / or there is no irrigation delivery system, but still some limited settlement and cultivation.
c) Improvements to a *working* tank to increase its existing storage capacity or to expand it's cultivated command area or both (i.e. raising of the bund and spill and improvements to the tanks sluices and delivery systems).
d) Refurbishing an existing *working* tank with no modifications to its storage capacity and or command area (usually maintenance or strengthening of the bund and spill way).

This shift in emphasis accelerated after 1978, with substantial state investment under several large-scale development programs with responsibility for project implementation devolved to divisional administrations. Three governmental and two NGO projects are most noteworthy in terms of scale or development impact. A brief outline of these programs follows (see also Appendix 1) and a comparison of various indicators of success are shown in Table 2[15].

A. Government Programs:

[15] On-going assessments are still required to assess the longer-term sustainability of all these programs.

1. The integrated rural Development project, IRDP (commenced 1979),
2. The Anuradhapura Dry Zone Development project (ADZAP1988 – 1992),
3. The Village Irrigation Rehabilitation Project VIRP (1980-1990)

These large-scale programs generally shared a top down 'blue-print' type approach and generally fell far short of their objectives. Considerable investment was made on physical improvements, increasing water availability to a certain extent. However in the area of farmer mobilisation for efficient water management and sustainable system management, little progress was made. The IRDP approach was the most organised, coordinated and integrated with other services and line agencies. The Hambantota program in particular achieved greater success in system management by adopting a more iterative and flexible 'rolling planning' approach. The ADZAP program targeted marginal *chenna* farmers, aiming to help them become permanent cultivators. However the program was highly politicised, bureaucratic and exemplified inefficient project planning design and implementation. Consequently finance was severely curtailed and impacts were low.

B. NGO Programs:

4. The Freedom From Hunger Campaign (FFHC) rehabilitation program (1980 - 1995)
5. The National Development Foundation (NDF) village tank rehabilitation program (1985 - 1998)

The FFHC is actually a public corporation, which adopted an 'indirect' NGO style of intervention. Some success was achieved in the area of farmer mobilisation and the adoption of a more integrated development package, but physical improvement to tanks was slow. The National Development Foundation (NDF) has adopted a much more dynamic approach to farmer mobilisation for both system improvement and management. Although only pilot scale in nature[16], this program has been widely acclaimed as a model for future development (IMMI 1996). Both these programs have successfully initiated the formation '*wewa sabhas*' (irrigation councils) resulting in much greater farmer participation than state strategies. However, the state 'blue print' type strategies score higher on their systematic monitoring and evaluation components. Dayaratne (1991) recommends that each of the following aspects should be considered when assessing rehabilitation strategies: system selection, farmer mobilisation, participation and ensured farmer leadership, integrated project planning, land consolidation, and good project management and coordination.

Although it is apparent that sustainable development of seasonal tank fisheries and efficient cultivation requires coordinated water management at the wider cascade level (see section 11), few if any integrated initiatives are taking place on this scale. The Bilateral (GoSL, SIDA) Anuradhapura Rural Development Program (ARDP) is a 5 year integrated program commenced in 1999 being implemented in over 200 cascades throughout Anuradhapura district. Integrated components include tank rehabilitation and fisheries (food and ornamental). However, beyond the initial watershed-mapping phase (contracted to IWMI), the above components appear to be being undertaken in a more or less *ad hoc* manner within the defined watershed boundaries. Currently, no where in the dry-zone of Sri Lanka are there any of the type of watershed development programmes which have become the norm in extensive semi-arid drought prone areas of India. Such programs are focussed around apexed people's institutions beginning at the street, village and finally watershed levels who take responsibility for a wide range of integrated activities including water management. Reasons for the lack of any such initiative may include the following:

a) Lack of government policy or any institutional agency with responsibility for development at suitable watershed scales compounded by lack of vertical or horizontal integration of existing line agencies

[16] The program has assisted improvement in 12 cascade systems of Puttalam district.

b) Superior water potential in Sri-Lanka's semi-humid agro-ecological context (Working Paper SL1.1) compared to most of the semi-arid drought prone areas in India
c) Existing presence of the physical structures for soil and water harvesting (i.e. tanks), the lack of which represent a central catalyst for stimulating community based institutional activity in the Indian programmes.
d) Although researchers have been expressing a need for watershed approaches since the mid-1980s (Sakthivadivel 1996), lack of knowledge and effective dissemination of existing knowledge continues to be a constraint.

CARE International, collaborators in this research, have recognised the need for watershed management in planning for a 'Dry Zone Agricultural Development project', a 6-year programme scheduled to commence in 2001. It is envisaged that this research will inform this and other similar rural development projects. A summary of the current status of watershed management in Sri Lanka is included in Appendix 2.

Table 2. A comparison of different minor tank rehabilitation strategies. (Source: Dayaratne 1991).

	VIRP [1]	KIRDP [2]	HIRDP [3]	ADZAP [4]	FFHC [5]	NDF [6]
Location	**Most of LDZ [7]**	**Kurunegala**	**Hambantota**	**Anuradha-pura**	**LDZ [7]**	**Puttalam**
No sites planned	1,700	500	19	132	222	16
No. completed	1,489	453	18	87	135	10
Time span (yrs.)	8	10	10	8	10	5
No. of beneficiaries	31,000	25,000	1,385	4,000	3,089	172
Area developed	20,000	11,554	1,682	6,480	4,390	88
Cost per hectare ($)	804	171	509	1054	275	325
Cost per family ($)	518	79	618	1708	389	166

[1] Village irrigation project, [2] Kurunegala integrated rural development program.
[3] Hambantota integrated rural development program. [4] Anuradhapura Dry Zone Development project.
[5] Freedom From Hunger Campaign. [6] National Development foundation. [7] Lowland Dry Zone.

7 Hydrology of small-scale tank systems

The hydrological endowment of an STC is based upon the spatial and temporal distribution of rainfall, surface and groundwater potentials (Dayaratne 1991). Tenekoon (1986) suggests that the importance of cascade level hydrological linkages were well understood by early settlers, as reflected in the following planning principles applied by farmers during STC construction:

- An adequate volume of water in every tank, even during years of below average rainfall.
- Instituting a regulated downstream flow of water to minimise the risk of bund breaching.

This implies there was an implicit understanding that altering the hydrology of one or a few tanks could alter the hydrology of the whole cascade. However Sakthivadivel (pers. comm.) suggests that most tank cascades came into existence over extended periods, being built more often according to social than hydrological factors and it is unusual to find compatibility between tank, catchment and command area. The consequences of such incompatibility have become more pronounced in the context of increased pressure on limited land and water resources and increasing drought frequency (see Working Paper SL1.1)

Ideas expressed by farmers during our research for improving the productivity of their irrigation systems, consisted primarily of physical options: tank excavation (de-silting) or increasing bund height to increase tank capacity and installing pumps to increase draw-down potential. This is indicative of a widespread prevailing dependency culture, a legacy of the centrally planned era (see section 7.2). Most farmers interviewed, did not think beyond the limits of their own tank(s) and generally had a poor perception of the consequences that their management or rehabilitation strategies might have on other downstream or upstream users within the same cascade. In one instance this created conflict between two communities arising from the partial inundation of command area following the rehabilitation of a lower tank. The potential of uncoordinated rehabilitation activities to move water-deficits downstream[17] was much more poorly perceived, probably due to the reduced visibility of such impacts against the background of highly erratic seasonal water availability.

Box 3: Some key findings of studies on small-scale tank hydrology in Sri Lanka.

Surface and ground water recharge: The percentage of rainfall intercepted by the catchment varies depending on the season, type of vegetative cover, topography and soil type. In a study of small tanks in Anuradhapura over four seasons, Somasiri (1982) showed that approximately two thirds of annual tank storage derives from run-off and one third from direct rainfall on the water surface. Total runoff is greatest during the main (*maha*) rainy season, varying between as much as 25% and 5% of rainfall during the *maha* and *yala* seasons respectively. Somasiri (1993) reported that runoff from scrub jungle and mature *chenna* averaged 2% of the maha rainfall whilst runoff from newly cleared *chenna* averages 25%. Dharmasema (1991) reported that the field capacity[1] of Red Brown Earths is 150mm. This amount of rainfall must be absorbed before useful runoff occurs. Soils tend to progress from more porous RBE's in the upper watershed, to relatively impermeable Low Humic Gleys (LHG's) in the lower watershed, contributing to the increased seasonality observed in upper catchments. Somasiri (1982) concluded that the irrigation potential of small tanks under forested catchment could be considered as favourable when greater than 10ha of catchment area exists for each hectare of tank capacity at 1m depth. Such tanks can attain full supply level during 40-75% of maha seasons.

Water balance: Itakura (1993) carried out the first water balance study for a whole dry zone cascade. Over two seasons he found that drainage return flows[2] over two *maha* seasons increased from 23% in the middle of the valley to 29% for the lowest tank, reflecting greater potential for water storage in the lower catchment. Average catchment run-off varied from 30% to 12% in *maha* and 10-4.5% in *yala* Return flows during *yala* were zero, therefore hydrological linkages between different tanks in this STC existed only during the *maha* season.

[1] The amount of rainfall a soil can intercept before it becomes saturated and surface runoff commences.
[2] Surplus irrigation waters draining from the command area immediately above a specified tank.

Most institutional rehabilitation planning continues to be based on hydrological assessments at the individual tank rather than the cascade level. Routine assessment is based on available meteorological data, topography, geology and limited hydrological measurements but no assessment of the potential of surface water or ground water recharge is made. There has been no systematic attempt to collect and organise hydrological data for any portion of Sri Lanka's Dry Zone (IIMI 1998). Poor understanding and inadequate data have contributed to the disappointing record of many small tank rehabilitation efforts in the past. The number of studies on small-tank hydrology to date is extremely limited (IIMI 1996). A summary of some of the key findings of several of these studies are shown in Box 3

As collection of primary hydrological data is complex and time consuming other simple indicators are required for planning purposes. The four main parameters determining surface water availability are; a) direct rainfall, b) rainfall runoff, c) drainage return flow, d) spill

[17] Sakthivadivel (1996) found many lower tanks received no spill water during 1-2 of every ten years.

water from the upstream tank[18]. Using these indicators Sakthivadivel (1996, 1998) has evolved a simple methodology for rapid assessment of STC hydrological endowment, based on a study of 310 tanks in the Anuradhapura area. This is described in the following section.

7.1 Small tank rehabilitation planning at the cascade level.

Two simple, rapid methods of assessing hydrological endowment of STCs for planning purposes are described, which rely on a combination of assessment of ordinance survey maps and farmer interviews:

Topographical Classification method: This is the simplest method based on an interpretation of 1" (or 1:500,000[19]) ordinance survey maps (IMMI 1996) available from the GoSL survey Department. First the form of the cascade (linear or branched) and size class, based on the total area of the meso-catchment, is defined. Size classes range from small (<1,000ha), medium (1,000 to 2,000ha), large (2,000 to 3,000ha) to very large (>3,000ha). A form index is calculated from the overall area to length ratio. Further subdivision then takes place based on the configuration of the main valley axis and side valleys. Where the slope of the axis is gently undulating (2-4% slope) there is greater water retentivity than when it is moderately undulating (4-8%). As the number of side valley's increases, usually so does the overall tank density within the cascade. This in turn tends to reduce the ratio of catchment to tank water spread area. However, tanks at the confluence of branches tend to benefit from increased inflow. Thus, hydrologically better-endowed STC's tend to have a combination of a linear or slightly branched form (with a higher form index) and a gently sloping gradient of the main axis.

Cascade water surplus method: Sathivadivel (1997) suggests a methodology for assessing rehabilitation potential based on the 'cascade water surplus'. This is the quantity of water discharged annually at the base of the cascade after satisfying the upstream demand for agriculture and other consumptive uses. The following indicators required to assess water surplus can be derived from historical data collected from farmers.

> *i. Cropping intensity (CI):* This gives a rapid indication of a tank's current agricultural performance and is an integrated method, i.e. combines land, water, technical and socio-economic factors allowing checking of the overall hydrological endowment of an STC. It is calculated by dividing the area irrigated during the *maha* season by the total command area under the tank[20]. A time averaged CI is calculated for each tank over the previous 5 *maha* seasons based on farmer responses. The 'cascade CI' is calculated by weighting the individual tank results obtained above, by the fraction of the total command area under that tank and results for the whole cascade totalled. The CI of individual tanks generally decreases with movement up the main valley, as tanks become progressively smaller and water availability more erratic.
> *ii. Ratio of tank catchment area to waterspread area[21] (CaW)*: This gives a measure of the hydrological potential of a tank. As a rule of thumb, tanks with a ratio less than 7.5 have little room for improvement.
> *iii. Ratio of command area to waterspread area (CoW)*: This gives a measure of adequacy of tank capacity (a ratio of less than 1 indicates sub-optimal cropping intensity).

A hydrologically well-endowed tank is one with the greatest capacity for increasing CI above its present value. CaW and CoW are purely physical assessments can be combined with the

[18] Supplementary diversions are occasionally made from another tank or river
[19] Availability of maps at this scale is often restricted for security reasons.
[20] Only the maha season is considered as yala cultivation rarely exceeds 1-2 years in every 10 in the dry zone due to low water availability
[21] Assumptions are based mean depth of 1m at maximum waterspread (a conservative estimate reflecting the generally shallow nature of most seasonal tanks in Sri Lanka).

CI to determine what combination of managerial or physical recommendations for improving agricultural productivity should be made. For example, tanks that have a CI of almost 1 and little potential for expanding the command area, (i.e. CaW < 7.5) should not have their capacity expanded. Recommendations for meso-catchments with surplus water include increasing the number or capacity of tanks. In deficit basins such interventions may simply move a deficit problem up and down the cascade. Management approaches to improving the efficiency of water use, especially in deficit situations, include the use of other field crops (OFCs), which have lower water requirements than paddy cultivation.

A regime of planning and maintenance based on the above principles could improve the availability and efficiency of water distribution within cascade systems. However the model values water only in terms of its primary use for irrigation. For example, whereas increasing storage capacity in surplus cascades may improve irrigation potential, it may also impact negatively on fish migration and natural recruitment through reduction in the frequency of spill events or through creation of migration impediments such as spillways.

A more comprehensive water resource profile reflecting the multiple-use characteristics of water (see section 14), must consider a wider range of hydrological aspects. With respect to fish production, most significant are seasonality (including minimum water spread, drawdown depth) and spill characteristics (frequency, volume and duration). Annual coefficients of variance and historic indices of these factors would inform planners about potentials and risks associated with specific development approaches. This could be combined with a cost benefit analysis, which values and compares the value of water for the range of producible goods and services, including enhanced fisheries or aquaculture production. Such an analyses, based on a Total Economic Valuation methodology (TEV - Pearce, 1993; Randall, 1991) has been undertaken for irrigated agriculture and reservoir fisheries in the Kirindi Oya irrigation system (KOISP) in Southern Sri Lanka (Renwick, 2000). Results indicated that fisheries represent an important economic contribution of the KOISP, adding approximately 18 percent of the value of KOISP's annual paddy production over the 1989-97 baseline period after all the associated costs of production were discounted.

7.2 Water access and ownership

Key policy events over the last four decades which impacted on farmer's access to and ownership of minor irrigation systems are listed in Box 4.

Prior to 1958 most village tanks were common property resources (CPRs), which were managed by village-level institutions. A system of rules, regulations and customs existed, pertaining to the management and maintenance of these resources and an irrigation headman the '*Velvidane*' held responsibility for their implementation, including fishery regulation. As the Sri Lankan economy moved to a progressively more centrally planned socialist model from the 1950s, all but the smallest STC's became state owned. The DAS who assumed responsibility for minor water bodies never had the resources, financial or human to take on this role. As the old management systems were abandoned, key activities like tank de-silting became more erratic and operational efficiency began to decline. The government tried to address the problem through stimulation of institutional responsibility at the village level including an attempt to re-instate the position of *Velvidane*[22]. However it has proved difficult or impossible to re-instate the sense of community ownership that had been lost earlier. All farmers interviewed during field work felt that the government continued to be responsible for upkeep of the their village tanks, except for the simplest maintenance. A situation where tanks are progressively allowed to deteriorate until 'rescued' by a government or NGO rehabilitation program clearly has longer-term negative impacts for all productive uses of

[22] The position has persisted despite lack of formal recognition, though it's importance has gradually diminished as part of wider trends in land and water access and ownership.

water. However, in the short term benefits may accrue to fisheries as farmers abandon cultivation of their land, or cultivate less intensively, resulting in greater persistence and less erratic fluctuation in the volume of water stored. Silting-up of the tank may also increase primary productivity levels, spill frequency and, consequently fish recruitment and yield.

Box 4. Impacts of Government of Sri Lanka policy on ownership and access of minor irrigation systems (Source: Economic Review 1994)

- Prior to 1958.Tanks were communally managed by farmer associations under the leadership of an elected *Velvidane* or the irrigation headman. Maintenance responsibilities were based on command holdings, with obligation to contribute to tank de-silting and bund maintenance on a *pro-rata* basis. Agricultural and fisheries production systems were subsistence low input / output but highly sustainable (Ulluwishewa 1995).
- 1958. Under the Paddy Lands Act No 1 – Cultivation committees responsible for water management replace the position of the Velvidane whilst major maintenance operations become the responsibility of the DAS. Loss of farmer's sense of ownership and responsibility accompanied by increasingly negative effects on maintenance and operation.
- 1972. Under the Agricultural Productivity Act, 4,000 Cultivation Committees are abolished and replaced with functionally similar Agricultural Productivity Committees with the election of new government.
- 1979. Under the Agrarian Services act, Agrarian service committees are established comprised of farmer and government representatives. *Velvidanes* are again appointed, but usually by political affiliation, with minimal impact. Development focus exclusively on extending command areas for intensified paddy cultivation.
- 1980's. Bilateral development emphasis shifts to integrated development improved water use efficiency and greater equity of benefits through multiple usage. Farmer organisations encouraged to manage tank resources with limited success. Major and widespread investments in tank rehabilitation as components of Integrated Rural Development Programs.
- 1990's ADB small-scale tank maintenance program implemented in North Central Province.
- 1999 Anuradhapura Rural Development Program is the first program to attempt coordination of water management at the cascade level cover, targeting over 200 cascades.

8 Other small-scale farmer-managed water resources in the Dry-Zone.

The groundwater revolution that has taken place in semi-arid arid areas of India with the recent advent of cheap pumping technology and subsidised electricity has not occurred to the same extent in Sri Lanka. Nevertheless, farmers in the Dry Zone are increasingly exploiting ground water resources for micro-irrigation mainly employing concrete-lined agro-wells (see Appendix 4) with the active participation of many development agencies.

These structures and other commonly encountered water bodies in study villages, including flooded quarries and borrow pits (see Appendix 4), were assessed for aquaculture potential.
Other novel small-scale, soil and water storage systems characteristic of watershed development in semi-arid areas including India have been slow to materialise in Sri Lanka (see Appendix 2).

8.1 Ground water sources and small-scale irrigation.

The distribution of groundwater is related to geological conditions and rainfall intensity, based upon which the country can be divided into 3 hydro-geological regions (Appendix 1). Ground water has traditionally been exploited for domestic use by excavation of small ground or tube wells[23]. However, over the last decade there has been a proliferation of larger shallow dug agro-wells[24] used primarily for small-scale irrigation. Agro-wells are often constructed immediately beneath tank bunds, or even within the tank draw down area where the water table is likely to be closest to the surface. Although such location implies an implicit awareness of the importance of STCs to groundwater recharge, never was this made explicit by farmers when asked to value their different uses of tank water (see section 14).

Typically agro-wells range from 2-5m in depth, usually providing a perennial source of water. However, over-exploitation has been reported as a worsening problem, particularly in the Jaffna region where there is greatest reliance on ground water. In the study area, the practice of pumping additional irrigation water below the tank dead storage level was reported to have negative impacts on water availability within adjacent agro-wells. A simple method for estimation of the sustainable level of ground water exploitation under STCs is shown in Appendix 1.

Although groundwater quality in most areas is generally good and relatively constant throughout the year, high fluoride and iron levels in some regions, including Anuradhapura and Hambantota, can make water unfit for human consumption. Biological contamination affects all regions particularly where the soil is thin. In densely populated coastal regions abstraction is uncontrolled resulting in brackish intrusion in many instances. In the Kalipitya and Jafna peninsulas extensive contamination of ground water with nitrates has resulted from excessive application of agro-chemicals. Faecal contamination from septic tanks and pit latrines has also been reported in the Jaffna Peninsular. Such factors generally represent negligible constraints to aquaculture, indicating good potential for alternative or integrated usage. In a recent GTZ Integrated Rural Development Program, agro-wells have been used with some success to produce fingerlings for seasonal tank stocking programs. Difficulty in successfully harvesting mature fingerlings from deep wells is reported as a constraint (Backhouse GTZ pers. comm.).

PART II

Results of Rapid Rural Appraisals in two cascade systems of NW Province

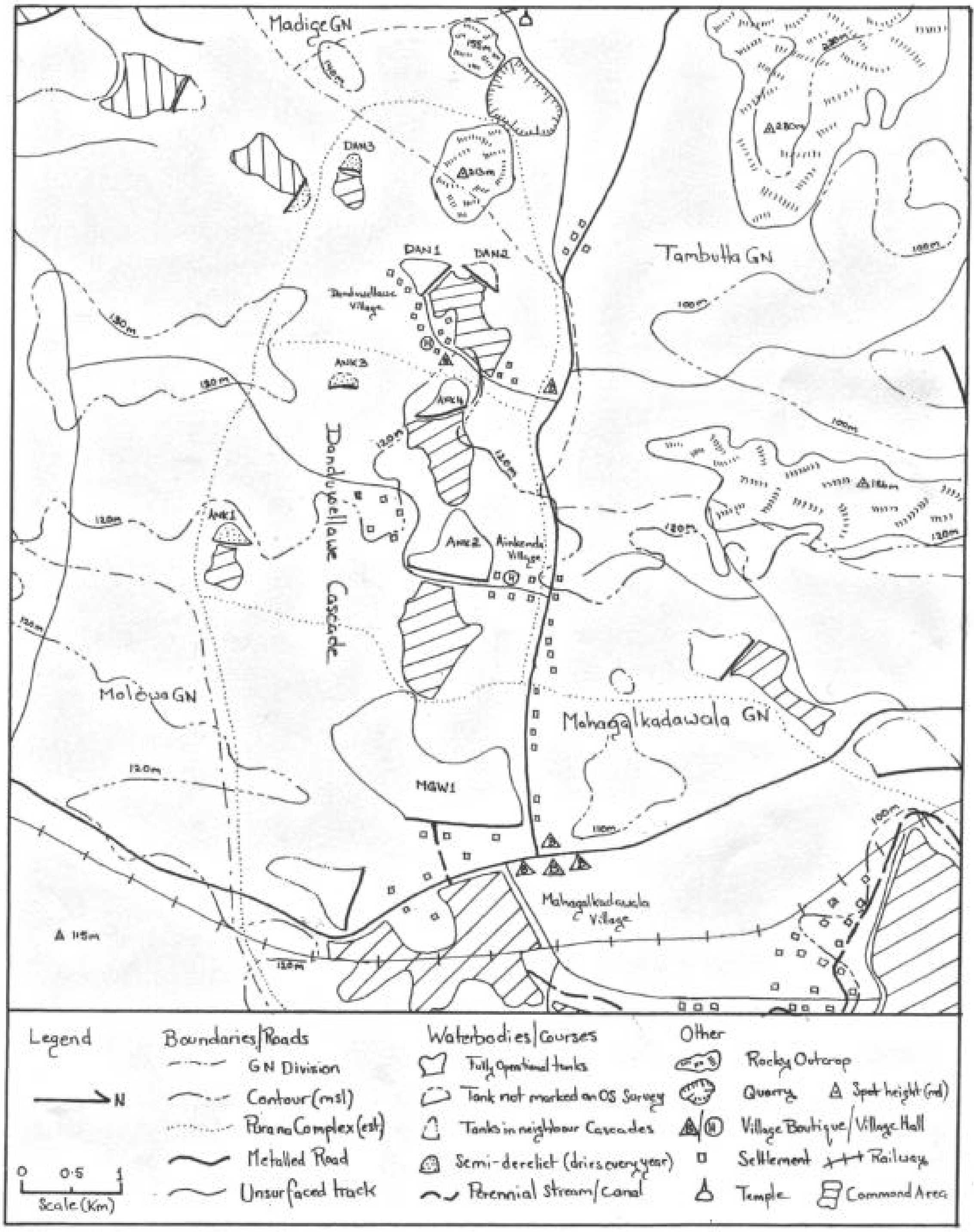
9 Danduwellawe and Pahala Diulwewa; the cascade systems

Schematic representations of the two cascade systems, including tanks, village and administrative boundaries are shown figures 5 and 6. Tables 3 and 4 present all the tanks surveyed within their cascade-hierarchical order (from top to bottom) along with reference codes and access details (see also section 13). Micro-watershed areas and gradients were calculated from contour details on the 1:500,000 survey maps. One village and their associated tanks from each system were selected as the primary sites for research. Danduwellawe was selected as the uppermost and most marginal of the three villages in the DDW system whilst Pahala Diulwewa in the middle of the PDW system was selected because of the village entry point provided by the NGO CARE (see Working Paper SL1.1). Following, is a description of the main physical characteristics of these systems.

[23] Most ground wells range from 3-20m in depth, fluctuating by up to 5m over the course of the year.

[24] Most agro-wells range from 3-5m in diameter and 3-5m depth. Larger wells are typically of brick or concrete construction and are used primarily for supplementary irrigation of OFCs.

Figure 5. Map of Danduwellawe STC, showing administrative and kinship boundaries (based on 1:500,000 survey maps, ground and farmer triangulation). (See Table 3. for key to tank identification codes).



Danduwellawe (DDW) STC:

Table 3. Summary characteristics of Danduwellawe (DDW) small-tank cascade.

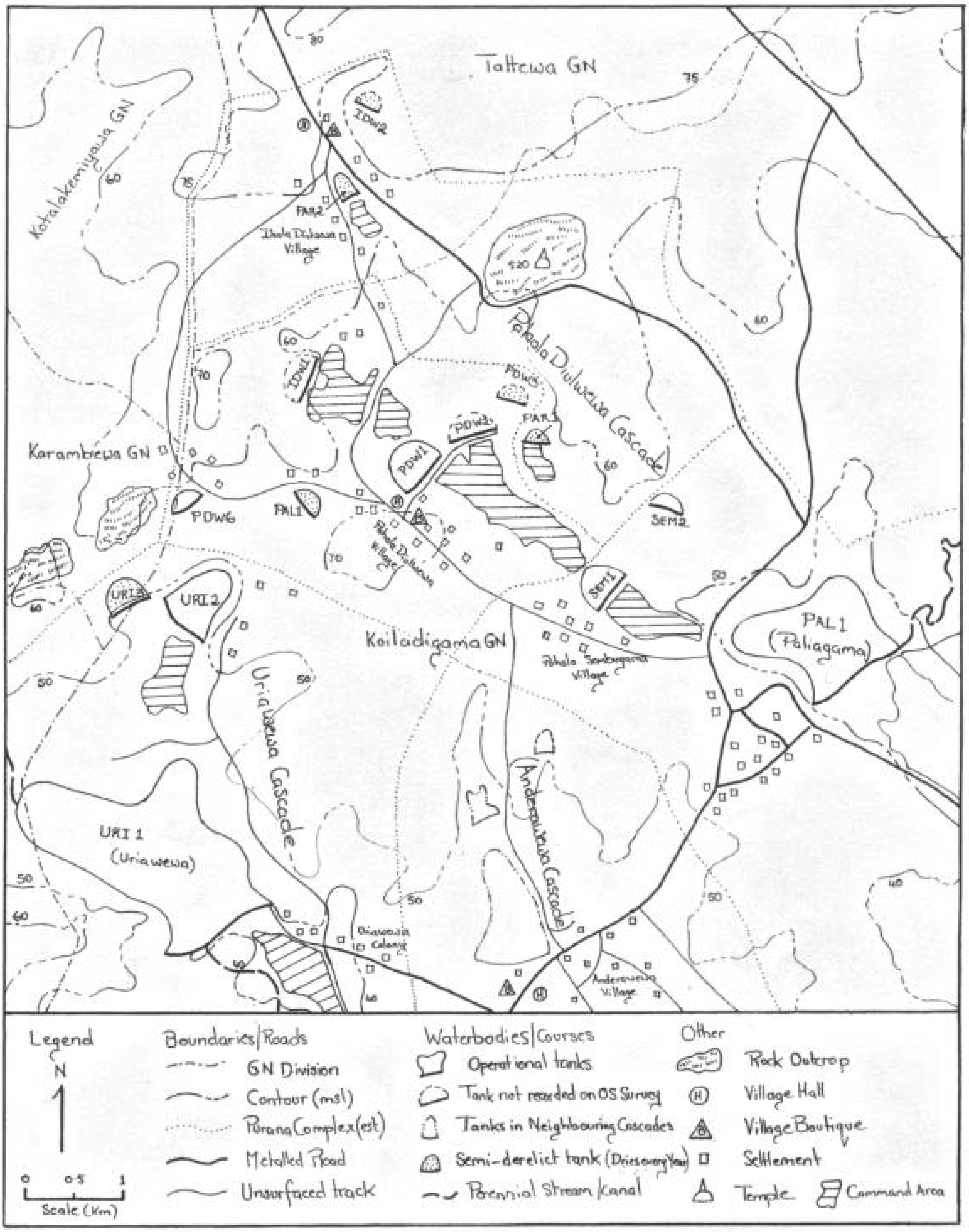
Tank Ref Code	Tank Name	Under control of which village?	Type of Tank[1]	Household No's[2]	N [3]	Access
DAN3	Aluthwewa	Danduwellawe	R	0		CPR
DAN2	Bundapuwewa	Danduwellawe	R	0		CPR
DAN1	Mahawewa	Danduwellawe	A	32	18	CPR
ANK4	Ankendawewa	Ankendawewa	A	19	4	CPR
ANK3	Kottagasyawewa	Ankendawewa	R	0		CPR
ANK2	Kumbukwewa	Ankendawewa	A	80	4	CPR
ANK1	Rathmale wewa	Ankendawewa	R	20	2	CPR
MGW1	Mahagalkadawewa	Mahagalkadawewa	A	226	4	CPR
	Totals			377	33	CPR

[1] Axial tanks (A) receive spill and drainage waters from up-stream tanks, whilst radial tanks (R) receive water only from their immediate micro-catchments..
[2]Households adjacent to the tank and using it as primary resource for daily activities including bathing and domestic uses.
[3]N = No. Farmers Questioned during RRA, each representing an in dividual household.

At slightly over 400ha, the cascade is a small[25], highly linear system, consisting of 4 larger tanks in the main axis and 4 small highly seasonal radial tanks. The terrain in the watershed is moderately sloping (between 2-4%[26]). Soils are sandy loam to medium lateritic red brown earths progressing to low-humic gleys in the lower watershed (DAS, Galgamuwa). At the top of the watershed is a steeply forested rock outcrop containing an ancient sacred religious site and a recently developed quarry. An aquifer at the foot of this outcrop augments the water supply of two of the uppermost tanks (DAN1 and DAN2) for up to two months post-*maha* rains. Together these two adjacent tanks irrigate the combined command area of the highest village in the watershed, Danduwellawe (DDW). Surplus spill and drainage waters then flow through progressively larger tanks, ultimately to Mahagalkadawewa[27] the largest tank in the system. Any surplus water along with drainage waters from the nearby Usgala Siyambalangamuwa (major) reservoir to the East, discharge into the Siyambalangamuwa canal. This in turn joins the Kala Oya (river), which flows into Rajangane Reservoir some 4km to the North. This large reservoir is part of the Mahaweli H system (see Section 4 and Working Paper SL1.1). All but one of the radial tanks (DAN2), have been abandoned for cultivation but are still used for a variety of ancillary purposes (see section 15).

[25] Under 2,500 acres total meso -catchment area (Sakthivadivel 1996 – see Section 7.1).
[26] Calculated from 1:50,000 survey map (GoSL Survey office).
[27] Wewas is the Sinhalese word for Tank.

Figure 6. Map of Pahala Diulwewa STC, showing administrative and kinship boundaries (basedon 1:500,000 survey maps, ground and farmer triangulation). Note: Part of a second (Uriawewa) STC is also shown to the west. (See Table 4. for key to tank identification codes).



Pahala Diulwewa (PDW) STC.

Table 4. Summary characteristics of Pahala Diulwewa and Uriawewa Small Tank Cascades.

Tank Ref Code.	Tank Name	Under control of which village?	Tank type	Household No's	N [1]	Tank Ownership & Access [2]
Pahala Diulwewa STC						
IDW3	Madatuwa	Ihala Diulwewa	R	3	0	CPR
IDW2	Ihala Diulwewa	Ihala Diulwewa	A	90	5	Temple
IDW1	Neluwawewa	Ihala Diulwewa	R	6	2	CPR
PAR1	Pinwewa	Ihala Diulwewa	R	5	1	Temple
PDW3	Siyambalagaswewa	PDW	R	2	1	Temple
PDW2	Ihala Sembugama	PDW	A	6	3	Private
PDW1	Pahala Diulwewa	PDW	A	52	20	CPR
SEM2	Koromdawewa	Sembugama	R	1	1	'Private'
SEM1	Pahala Sembugama	Sembugama	A	23	4	'Private'
PAL1	Paliagama	Paliagama	A	166	2	CPR (DAS)
Uria wewa STC						
PDW6	Ulpathwewa	PDW	A	10	3	'Private'
PDW5	Keeriyagahawewa	PDW	A	0		'Private'
PDW4	Palugas	PDW	A	2	1	'Private'
URI 3	Morankulamwewa	Uriawewa	R	1	1	'Private'
URI 2	Wayrankulamwewa	Uriawewa	R	40	3	CPR (DAS)
URI 1	Uriawewa	Uriawewa	A	255	2	CPR (ID)
	Totals			**630**	**49**	

[1] N = No. Farmers Questioned during RRA (representing individual households)
[2] Access and Ownership: CPR = Common property resource. DAS = Department of Agrarian Services. ID = Irrigation Dept.

The situation in this cascade is more complex as 2 villages, Ihala Diulwewa and PDW, the principal study villages, straddle more than one meso-catchment. PDW village benefits from access to two of the larger tanks in the mid-PDW watershed, in addition to several smaller tanks at the head of the neighbouring Uriawewa cascade. During years with heavy rains PDW tank also spills into Palugaswewa at the head of the Uriawewa system. Residents of the highest village Ihala Diulwewa have primary access only to seasonal and semi-seasonal tanks at the head of PDW, Uriawewa and Bammanegama (not investigated) cascades. Thus in the PDW system, administrative, social and intermittent hydrological linkages extend across it's watershed boundaries.

At slightly under 400ha total meso-watershed area, the PDW cascade also falls within the small cascade classification, but with four tanks along the main axis and 6 radial tanks to the South, the system is more radial in form than the DDW cascade. Paliagama the largest tank at the base also receives cascade waters from two tanks in a neighbouring micro-catchment, which were excluded from this analysis. The adjacent Uriawewa system is a highly radial system with 3 separate micro-catchments flowing into the base tank. The base tank Uriawewa is a 'system' tank (see section 5) with supply augmented via a diversion canal from Inginimitya reservoir, a major irrigation system some 10km to the East. With a command area over 200ac, Uriawewa is classified as a 'medium' irrigation system under the remit of the Irrigation Department and therefore outside the intervention scope of this project. Waters form the Uriawewa and Paliagama base tanks drain into the Mi Oya (river) via the Ravi

Benda Ela (an anicut system) and ultimately the sea some 30km away. As in the DDW system, a rocky outcrop with a religious function, this time an ancient temple, is located at the top of the meso-watershed. Four villages are associated with the PDW cascade, whilst tanks in the Uriawewa system are managed by villages in neighbouring watersheds and farmers from the rehabilitation colony under Uriawewa itself. Summary characteristics of all the cascade systems are shown in Table 3 and 4, with tanks again presented in cascade-hierarchical order.

10 Hydrological endowment in DDW and PDW STCs

Both of the study systems are located in the Low Country DL1 agro-ecological region (AER), where they receive highly erratic rainfall, some 70% of which falls during the *maha* season (October to January) - see Working Paper SL1.1). Mean annual rainfall in the DDW area is 770 mm per year (at 75% probability) falling as low as 330mm (DAS office Galgamuwa). The PDW system is immediately adjacent to the wetter IL2 AER of the Intermediate zone receiving a mean of 900mm rainfall per annum, slightly higher than the DDW system.

Soil catenas are similar in both instances, with reddish brown earths dominating in upper watershed areas and black soils lower down. The density of tanks in the PDW cascade is greater than the DDW system but the terrain slopes more gently (<2%). Generally water retention is lowest in the upper tanks, due to the pattern of soil distribution and the steeper gradient at the top of the watershed.

The hydrological endowment of the different cascade systems was assessed using the method suggested by Sakthivadivel (1996) (see section 7.1). Catchment, water spread and command areas were calculated from the 1:500,000 ordinance survey map and triangulated with key informant interviews (DAS, Samurdhi and farmers). Farmers were also asked to recall spill frequencies and duration over the last five years, which was determined as the longest period with reliable recall. Cropping Intensity (CI) was determined by averaging farmers' estimates of the extent of command area successfully cultivated also over the previous 5 years (*maha* cultivation seasons). Results are presented in Tables 5 and 6.

Danduwellawe STC:
A low weighted cascade CI of 0.67, along with the generally low spill frequency indicates that little surplus water capacity is available. Other indices also reflect a generally poor hydrological endowment. Hydrologic potential (CaA/Ws) is low and the mismatch between tank capacity and command area (CoA/Ws) becomes progressively worse and irrigation supplementary, with movement up the catchment. This is consistent with the higher incidence of crop failure reported by farmers in DDW. Poor catchment management compounds these deficits. Immature scrub forest predominates, with few larger trees remaining due to illegal felling activities. Most of the highland cultivation and rainfed paddy formally undertaken in these areas has been abandoned over the last 3 years due to elephant incursions, allowing some temporary recovery.

Low spill frequencies and relatively high CIs at all levels in the main axis suggest further extension of tank capacity within the system would simply shift water deficits downstream. Rehabilitation efforts should therefore be confined to system maintenance and operational improvements. In this context competition between alternative water uses, particularly between fisheries and the primary use for irrigation is likely to be more intense than in the more generously endowed PDW system (see below). Farmers under DDW and Ankendawewa tanks reported that they had pumped water from the dead storage area for emergency irrigation during two of the previous five years.

Table 5. Hydrological Endowment of Danduwellawe Small Tank Cascade (Source: farmer interviews, interpretation of 1:50,000 survey maps & field observations)

Tank Name	Hydrologic Indices[1]						Spill Freq. (n/ 5yrs)	Seasonality[2]	Dead storage area (ac)	Max depth (ft)
	CaA (1)	WS (2)	CoA (3)	CaA/ Ws (4)	CoA/ WS (5)	CI (6)				
Main Axis Tanks										
Maha	52	9	21	5.78	2.33	0.74[12]	3	SS	2	10
Bandapu	33	5	14	6.60	2.80		1	SS	0.5	8
Ankenda	94	12.5	18	7.52	1.44	0.8 [3]	2	SS	4	10
Kumbuk	205	30	36	6.83	1.20	0.78[3]	2	SS	1	13
Mahagal kadawala	450	70	60	6.43	0.86	0.82[3]	3	P	10	15
Radial tanks (All command areas abandoned)										
Aluth	12	2	5	6.00	2.50	0 [1]	5	HS	NA	2
Rathmale	28	4	11	7.00	2.75	0.15[2]	5	S	NA	6
Kottagas	-	-	-	-	-	0 [1]	5	HS	NA	2
Totals	**874**	**132.5**	**165**			**0.668**	**:Weighted Cascade CI (7)**			

[1] (1) Catchment area (ac), (2) Max. tank water-spread (ac), (3) Command area (acres) (4) Hydrologic potential (5), Adequacy of tank capacity, (6) Cropping Intensity (7) Weighted cascade CI = (Sum of (6)*(3))/ Sum of (3). [No. of respondents].
[2]Seasonality: HS = Highly seasonal (dries every year), S = Seasonal (dries at least once every 5 years), SS = Semi seasonal (dries less than once every five years, P = Perennial (never dries).

***Pahala Diulwewa and Uriawewa STCs*:**
Higher spill frequencies and CI's for these cascades (7.6 and 8.6 respectively), indicate a greater hydrological endowment than in the DDW system. At 0.13acres of waterspread per acre of catchment area, mean tank density is the same in both DDW and PDW cascade systems[28], and the difference is probably a consequence of higher annual rainfall levels and higher water retention in the lower gradient PDW system. The high CI of the Uriawewa cascade is disproportionately affected by the inclusion of Uriawewa, a large system tank, masking the highly seasonality of many small tanks located in it's upper-watershed.

Hydrologic potentials (CaA/Ws) in the PDW system are again low (mostly < 7.5), but the overall endowment is superior to DDW as reflected by higher spill frequencies. Pahala Sembugama tank is located at an important mid watershed confluence. It has a low CI, and one of the highest spill frequencies indicating good potential for capacity enhancement. However this would require the more expensive option of de-silting as bund / spill heightening risks inundation of the adjacent command area immediately upstream. Earlier augmentation of the storage capacity of the two immediately superior tanks (see Table 7) has had no apparent negative impacts on water availability in Pahala Sembugama. This suggests that a degree of hitherto un-harnessed surplus water capacity in the system has been successfully harnessed as a consequence of this rehabilitation work.

In terms of water availability, the semi-seasonal mid-level catchment tanks such as PDW and Kumbukwewa would appear to show greatest potential for aquaculture and enhanced fisheries. These tanks rarely dry-out totally, but shrink to a modest 1.2-1.6 ha (mean depth 1m) of residual water spread during most years facilitating easy harvesting. However a different pattern emerges with respect to accessibility to water resources and other technical constraints such as aquatic weed encroachments (see sections 14 and 16).

[28] though density is slightly greater in the upper part of PDW cascade

Spilling of water is more frequent during the *maha* season (see Tables 5 & 6) and much less likely in the *yala* season. Of all the tanks surveyed, none in the DDW cascade and only the shallowest seasonal tanks in PDW (Ihala Diulwewa, Pinwewa and Palugas) were recorded as having spilled during *yala* seasons over the last 5 years. *Maha* spill events take place mostly between November to January, whilst smaller *yala* events occasionally take place between April to May. Generally spill frequency is greatest in the shallowest seasonal tanks but the duration and volume of individual spill events tend to be greater in larger lower tanks e.g. the last recorded *maha* spill event in Uriawewa lasted for over 1 week. Spill frequencies are generally greater in the PDW system with its greater hydrological endowment. This has critical consequences for fish migration and natural recruitment (see section 11).

These observations indicate a need to reassess the relative costs and benefits of tank rehabilitation based on changing hydrological patterns and the differing priorities accorded to a multiple range of water uses at different levels of the cascade. Trade-offs will exist between, de-silting and bund enlargement, whilst the excavation of fish refuges in residual water areas below the bund may be highly compatible with improving bathing potentials in the more seasonal tanks.

Table 6. Hydrological Endowment of Pahala Diulwewa Small Tank Cascade (Source: farmer interviews, interpretation of 1:50,000 survey maps & field observations)

Tank Name	**Hydrologic Indices[1]**						**Spill Freq. (n/ 5yrs)**	**Seasonality[2]**	**Dead storage area (ac)**	**Max depth (ft)**
	CaA (1)	**WS (2)**	**CoA (3)**	**CaA /Ws (4)**	**CoA/ WS (5)**	**CI (6)**				
Pahala Diulwewa STC										
Main Axis Tanks										
Ihala Diulwewa	21.3	6	5	7.1	1.4	5.6 [4]	5	SS	2	6
Ihala Sembugama	73	8	14	9.1	1.73	6.3 [4]	5	SS	2	9
Pahala Diulwewa	139	19	39	7.3	2.05	7.4 [9]	2	SS	8	10
Pahala Sembugama	65	12	23	5.4	1.9	6.7 [3]	5	SS	0.5	8
Uttura Paliagama	496	80	156	6.2	1.95	8.1 [2]	4	P	50	16
Radial tanks										
Neluwawewa	59	7	17	8.4	2.4	7.7 [2]	4	SS	3	7
Pin wewa	19.2	3	0	6.4	0	0 [1]	5	HS	0.25	6
Siyambalagaswewa	76	9	10	8.4	1.15	6.2 [1]	5	SS	1	7
Koromdawewa	16.8	3	0	5.6	0	0 [1]	5	SS	0.5	6
Totals	964	144	264			7.6	**:Weighted cascade CI (7)**			
Uriawewa STC										
Main Axis Tanks										
Morankulamwewa	29	4	0	7.3	0	0 [1]	3	HS	2	7
Uriawewa	528	110	204	4.8	1.85	8.9 [2]	4	P	25	20
Radial tanks										
Palugas	21	3.5	3	6.1	0.9	5.7 [2]	5	S	1	8
Ulpath	21	3	6	6.9	2.1	7.1 [3]	5	S	1	9
Wayeerankulam	110	15	20	7.3	1.3	6.7 [1]	4	P	4	8
Totals	**709**	**136**	**233**			**8.6**	**:Weighted cascade CI (7)**			

[1] (1) Catchment area (ac). (2) Max. tank water-spread (ac). (3) Command area (acres). (4) Hydrologic potential. (5) Adequacy of tank capacity. (6) Cropping Intensity. (7) Weighted cascade CI = (Sum of (6)*(3))/ Sum of (3). [No. of respondents].

[2]Seasonality: HS = Highly seasonal (dries every year), S = Seasonal (dries at least once every 5 years), SS = Semi seasonal (dries less than once every five years, P = Perennial (never dries).

11 Tank rehabilitation, watershed planning and fisheries

In addition to the primary goal of enhancing irrigation potential, other benefits arising from rehabilitation interventions, including the potential for marginal groups to renegotiate access to water resources and revitalisation of village institutions are well recognised. Illustrating the latter point; in Ihala Diulwewa members of the village youth group felt they had acquired the right to exploit fisheries in Madatuwa wewas, since this formerly 'private' tank had recently been rehabilitated with government funds.

Yet, rarely are potential impacts on fisheries or any requirement for mitigation considered during rehabilitation planning and such neglect is further compounded by lack of integrated management at the watershed level. At the level of the individual tank, positive impacts may be expected where rehabilitation results in increased dead storage capacity.

- Intensive fishing effort and drying episodes common in smaller radial and upper-watershed tanks can be followed by years with near total loss of production when no natural migration routes are available. Increased dead storage will enhance the likelihood of stock carryover.
- Reductions in spill frequency arising from storage enhancement may reduce the likelihood of losses where conventional stocking programs are implemented using costly hatchery reared seed.

However, in the context of poverty alleviation, low-input enhancements based on local seed availability and suitable habitat enhancement are likely to be the most adoptable and sustainable aquaculture options in the longer term (see Working Paper SL1.2). Rehabilitation measures can be expected to bring the following opportunities and constraints in this context:

- *Spill Modulation*: Interventions that reduce spill frequency or create physical obstructions (such as the construction of elevated concrete spillways) may have negative impacts on trans-boundary migrations and natural recruitment outweighing the benefits outlined above.
- *Modification of multiple use trade offs*: Farmer trade-offs between consumptive uses (i.e. irrigation) and non-consumptive uses (i.e. fisheries and bathing) are likely to be changed as a result of storage capacity modifications. For example, tanks hitherto largely abandoned for cultivation but supporting healthy fisheries may be brought back into production where threshold storage levels associated with acceptable cultivation risk are crossed. This may in turn have negative impacts on fisheries where the likelihood of emergency irrigation using dead storage is increased (see section 14).

A review of the rehabilitation interventions undertaken in the two research areas and their impacts in these different arenas follows:

DDW STC: All of the larger perennial and semi-seasonal tanks (>30 ac) had benefited from various degrees of recent rehabilitation (see Table 7). The most extensive work had been undertaken in DDW as part of an IFAD[29] /GoSL bilateral integrated development program during 1996. Physical interventions included; de-silting, increasing bund height and installation of concrete sluices, spillways and distribution channels. Bundapuwewa, which had earlier been abandoned due to heavy siltation, was completely rehabilitated and an additional area of irrigated paddy reclaimed under this and the adjacent Mahawewa tank. Anti-soil erosion measures including vegetative contour bunding were also facilitated. Although bulldozers were contracted for de-silting, farmers participated in bund and field distribution channel repairs and their involvement in the planning and implementation stages

[29] International Fund For Agricultural Development

has helped to strengthen the farmer's organisation[30] and improve collective water management (see section 15.1). As the command areas of all the main axial tanks are almost contiguous with the tank beds of lower tanks, little scope for further physical expansion of the irrigated area exists. Only in these two tanks had steps been taken to increase tank capacity, subsequent to which no spill events or natural fish movements had taken place between these and lower tanks[31] Prior to rehabilitation, both tanks had spilled regularly (2-3 years out of 5). Additionally, no consideration been given to impacts on downstream water availability.

Other tanks in the system had received less attention over the last 15 years. All had benefited from spill and sluice repairs and farmers from Ankendawewa had been encouraged to participate in repairs to the distribution system under the Samurdhi program. Cultivation under DAN1, ANK1 and ANK3 the smallest radial tanks had been abandoned over the last 5 years, due to heavy siltation. All are now highly seasonal. These tanks are located in the least populous parts of the watershed and are less cost effective to rehabilitate (DAS, Galgamuwa pers. comm.). Many families who do live here are illegally encroached into forestlands within the watersheds and are amongst the poorest in the area. Only Rathmalewewa is still an important resource for domestic and bathing purposes and is occasionally still fished for resilient air breathing species *A. testudinis* and *C. striata* (see Working Paper SL1.2).

PDW and Uriawewa Cascades: These systems differed markedly from the DDW system in their greater number of small privately and temple-owned tanks in the upper watershed area (see Table 4). However, most of these were in a similarly neglected condition, particularly the temple tanks. Rehabilitation initiatives taken in other tanks are shown in Table 7. Over the last 10 years only Neluwawewa, Pahala Diulwewa, Pahala Sembugama have had their storage capacity restored or increased. Wayarankulam had its bund strengthened and spill height lowered after a breach during the 1997 *maha* season. As in DDW these rehabilitation steps were undertaken on an intermittent basis with no apparent co-ordination between the various implementing organisations and with much of the labour and planning undertaken by outside contractors.

Only the superior hydrological endowment of PDW would appear to have mitigated some of the adverse impacts on spill frequency and natural recruitment observed in the DDW system. This is illustrated by anecdotal production accounts reported in Ihala Diulwewa and Mahawewa, small seasonal tanks at the top of the PDW and DDW cascades respectively. Both tanks dry completely on average once in every 5 years (see Tables 5 and 6) and are therefore dependent on recruitment from lower perennial tanks for sustained production. Whereas production levels in Ihala Diulwewa (no recent rehabilitation) have actually increased, lower production levels and loss of species diversity were reported in Mahawewa despite the fact that the tank has not dried completely since the tank was enlarged.

The above observations suggest various routes for increasing or sustaining existing production based on the enhancement of natural recruitment pathways which could be used to supplement the in-situ dry-season preservation of breeding stocks through refuge construction.

- *Removal of physical obstructions to migration pathways:* These could include the inclusion of simple fish passes during construction of spillways, or the clearance of obstacles from dry streambeds.
- *Rehabilitation planning at the watershed level:* Identification of the most strategic axial migration routes and preservation of seasonal spill events between these tanks.

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[30] Membership, frequency of meeting and collective cultivation activity all reported to have increased.
[31] The last 15 years was used as the maximum time period that reliable recall of hydrological events could be expected. However triangulation exercises resulted in this period subsequently being reduced to 5 years.

- *Stock enhancement.* This could be based on stocking strategic perennial or semi-seasonal tanks with fingerlings or broodstock that support the greatest number of migration routes to more seasonal tanks. In this instance the potential for escape during spill events becomes a benefit rather than a constraint. Alternatively the sourcing and movement of smaller numbers of broodstock to seasonal tanks above intermittent natural or man-made migration bottlenecks would represent the most extensive and low risk means of enhancement. Not surprisingly some local farmers have already adopted such a system. One farmer from Mahawewa (Danduwellawe village) commissioned a commercial bicycle vendor to bring a small number of live tilapia (around 50g) from Rajangane reservoir to re-colonise the tank after it dried completely during rehabilitation. Similarly one farmer from Ulpathwewa (PDW cascade) had also sourced a small number of tilapia, from the Uriawewa base tank. In many other instances children reported stocking their village tanks with a variety of species caught during recreational fishing events.

Further analysis of recent spill events (frequency, volume and duration) based on farmer recall correlated with rainfall data are required to better understand the likely fisheries impacts represented by different tank rehabilitation strategies.

Table 7. Tank rehabilitation history in PDW and Uriawewa cascades. (Source: key informant interviews)

Tank	Year	Agency	Rehabilitation steps
Ihala Diulwewa	1988	DAS	De-silted, bund strengthened, sluice repaired
Neluwawewa	1998	Govt	Bund heightened and sluice repaired
PDW	1963,77	Govt/GMD	De-silted and sluice repaired
	1997	ADB	Bund and spill repair, distribution pipeline installed, mechanical de-silting
Pahala Sembugama	1988	Govt	Bund height increased, sluice repaired
	1994	Samurdhi	Sluice and bund repair. Manual de-silting
Palugas	1960	Owner	Reclaimed from jungle by grandfather
Ulpathwewa	1997	CARE	Sluice repair
Wayrankulamwewa	1997	Owner	Mechanical repairs to bund.
Uriawewa	1948	DAS	Ancient tank – full restoration and resettlement
Uriawewa	1982	DAS	Bund, spill and sluices repaired

12 Water quality

Water and air temperature, pH and conductivity were measured *in situ* using a Hanna 9025 hand held pH meter. Where depth permitted, turbidity was measured using an improvised secci disk. Ground water resources (agro-wells and tube wells) and surface water bodies (tanks, paddy fields, borrow pits and drainage systems) were assessed at different levels of both cascades.

Although no longitudinal survey of water quality is possible in the context of an RRA, measurements were made at a time of the cropping calendar when levels of agri-chemical inputs were at their highest and ambient temperature elevated, allowing potential for identification of limiting water quality factors. However, time constraints had both a significant impact on the choice of water quality parameters, which could be measured, and the sampling strategy employed (ideally early morning and afternoon measurements would have been taken to gain an understanding of the diel cycles which occur in many physical parameters). Consequently the following results (see Appendix 5) must be treated as highly indicative. A longitudinal survey designed to gain a better understanding of primary productivity at different levels of the cascade system is the subject of a follow-up survey.

Table 8 shows countrywide trends in several physio-chemical parameters. Surface waters draining from the granite central hills of Sri Lanka are normally clear, soft and more or less neutral in pH. Lowland standing water bodies have higher levels of dissolved solids, conductivity and are generally alkaline. A wider range of pH values were found during our field measurements, reflecting the greater extremes in water quality that can be expected under seasonal compared to non-rainfed systems[32].

Table 8. Water quality in the wet and dry zones of Sri Lanka (After Pethiyagoda 1994)

	Central hills (riverine)	Lowland (static)
Clarity DH	2-5	NA
Conductivity	18-3 (uS @ 22oC)	400-1100 (uS @ 27oC)
PH	5.8-7	7.4 – 8.4

Ph levels generally fell within the optimum range for most aquatic species (between pH 6-8.5). However elevated levels were measured in and around the lower tanks. Chandrasoma (1986) showed positive linear relationships between fish yield and conductivity and alkalinity in ten seasonal reservoirs. De Silva (1988) reported a correlation between conductivity (uS at 25oC) and total dissolved solid levels in 20 reservoirs with levels ranging between 250-700 micro-Siemens (uS). He goes on to report that in most perennial water bodies, pH levels are neutral or slightly alkaline and remain relatively constant throughout the year. In the current study, the highest conductivity (and pH) levels were found on flooded paddy lands recently applied with inorganic fertilisers. Levels tended to increase lower down the catchment possibly due to a progressive accumulation of leached fertilizers, correlating with higher reported yields. Levels were generally lower in PDW cascade where little paddy field preparation or sowing had taken place at the time of measurement. High levels measured in several agro-wells, was probably a result of high salinity levels (as reported by farmers and confirmed by taste).

Tank Stratification was indicated by a large differential in pH, temperature and conductivity of surface waters of Mahagalkadawala tank and a sample taken at 4.5 m depth (via the sluice). At 9.02, the pH level at this depth was the highest recorded. As stratification patterns can cycle on a daily basis, diurnal assessments are required to assess the situation fully. Consistently elevated levels such as the one recorded could have negative impacts on the breeding success of many fish species.

Temperature levels fluctuated most dramatically in shallow paddy fields, with mid-day temperatures reaching nearly 35oC under Kumbukwewa. Such extremes are also likely to be great in the shallow receding waters of smaller seasonal ponds, where oxygen deficits may influence the choice of candidate species to 'blackfish' varieties tolerant of abiotic conditions (see Working Paper SL1.2).

Turbidity: Intermittent heavy rains during the sampling period resulted in high silt levels and low sechi disc readings in all water bodies receiving surface run-off. Highest levels were recorded in the smaller upper watershed tanks of PDW cascade shortly after rainfall episodes. Levels were generally lower under DDW cascade, due to the greater interval, which had elapsed between rainfall and measurement. Against a background of elevated silt loads and high dilution the contribution of primary productivity to turbidity levels was difficult to assess. Slight green colouration was observed only in agro-wells relying primarily on groundwater recharge and stagnant highly fertile water in paddy fields. Widespread encroachment and degradation of catchment areas [33] is likely to have increased silt levels and whilst causing a net reduction and increase in the organic and inorganic nutrient load of

[32] due principally to the erratic water availability and reduced dilution effects under seasonal regimes
[33] Principally through fixed upland cultivation in PDW cascade (reflecting the lack of primary forest in this area) whilst abandoned (though potentially more erosive) chenna plots were in greater evidence in DDW cascade.

waters flowing to lower tanks in the longer term. These factors represent a potential constraint to aquaculture options, which require good early growth to overcome short-growing seasons and high predation pressure on juveniles.

Agro-chemicals: Over the last 20 years 95% of farmers in Sri Lanka have switched from use of on-farm organic fertilisers and traditional pest management techniques to modern high-yielding rice varieties[34], (Koziell, 1998) requiring high levels of inorganic fertiliser and pesticide inputs (Ulluwishewa 1991) The highest use of pesticides occurs in irrigated areas. Although such inputs are used more extensively on OFCs, including vegetables, over two thirds of rice currently cultivated in Sri Lanka has herbicide applied and rice consequently consumes over 70% of the total application (*Steele et al*, 1997) Whereas sub-optimal application of inorganic fertiliser has been recognised as a problem, pesticides are generally applied above the recommended dose (IMMI 1998). Low concentrations of aldrin, dieldren and BHC were detected in samples collected from the Minneriya Reservoir in 1979 (CEA 1995) and Steele *et al* (1998) also report that chemicals have contributed to the decline of inland fish species living in tanks and rice fields (also see Working Paper: Taylor 1999). Concentration effects in seasonal tanks are expected to be high due to the relative lack of dilution in rainfed systems and downstream users are likely to experience the greatest cumulative water quality impacts, related to the amount and ratio of drainage and spill waters received. Longer-term effects on the ecosystem through bioaccumulation of toxic substances in the food chain are poorly documented. Within STCs the following factors, will determine the volume of drainage returns and hence downstream pesticide accumulation.

- *Seasonality:* Pest infestation and pesticide application rates are likely to be greater during rainy periods, particularly during the *maha* season when drainage returns are also highest.
- *Cultivation strategies and water management:* The choice of crop and the catchment location will be the main determinants of frequency and period of water issues. These will be lowest in the upper catchment areas.
- *Catchment management:* Factors that increase surface run-off, such as catchment topography, geology, and vegetative cover, are likely to increase downstream accumulation. Pesticide residues have a strong tendency to adsorb to colloidal material; therefore, poor watershed management and downstream conditions that favour deposition will affect pesticide accumulation rates. Larger particles are likely to be deposited within storage systems[35], whilst finer particles will find their way to the lower farm sub-systems. Bioaccumulation of persistent pesticides in bottom feeding species (i.e. common carp) and predators such as snakehead[36] may conceivably increase the risk of chronic pesticide poisoning in human consumers.

In conclusion, at the time of sampling most of the water quality parameters measured were in acceptable ranges for a wide range of locally available species with potential for aquaculture. However the greatest water quality constraints can be expected during the dry season when only 'blackfish'[37] species will be able to tolerate abiotic conditions in more seasonal tanks. It is recommended that future studies include a time-based assessment of oxygen, alkalinity, total and dissolved, organic and inorganic solids loads to assess both the effects of catchment degradation and to make estimates with respect to primary productivity and carrying capacity for different species assemblages.

[34] The number of rice varieties has dropped from 2,000 in 1958 to less than 100 today.
[35] Concentrating residues on the tank bed where they may be very persistent.
[36] An important component of the seasonal tank fishery - see working paper No. 3
[37] 'Limnophilic', still water species , highly tolerant of abiotic conditions. 'Whitefish' are 'rheophilic', flowing water species intolerant of low oxygen levels and likely to migrate downstream during to survive the dry season.

13 Community-Based Natural Resource Management (CBNRM) within the watershed.

13.1 Caste and kinship linkages and access issues

Kinship linkages within discrete caste demarcations observed in the cascade systems determine patterns of colonisation, which in turn help to explain the current forms of access to water and land resources at the village and watershed level. Two forms of rural settlement are commonly distinguished in the dry zone of Sri Lanka.

- *Irrigation settlements or 'colonies'* have been constructed over recent decades in tandem with the extensive development of major irrigation schemes. Often the size of a small town benefiting from good modern infrastructure, these settlements were developed to relieve population pressure in the hill country. They are typically populated by heterogeneous groups in terms of caste and kinship, despite some attempts to re-settle whole communities.
- *Purana Villages.* Traditional settlements in the dry zone known as 'Purana' (old or traditional) villages tend to be home to extremely homogeneous groups held together by strong ties of kinship. These older villages were usually established around more reliable perennial or larger semi-seasonal tanks. Farmers who settled in these villages went on to augment their cultivation strategies by extending irrigated cultivation to smaller more seasonal tanks adjacent to the base tanks, often on a rotational basis[38]. However, with increasing population and competition for limited natural resources farmers progressively begin to settle around these smaller tanks. Yet ownership of much of the irrigated land under these tanks and therefore control of water often continues to reside with more affluent farmers in the older Purana settlement.

In his seminal study of a single community in Anuradhapura District in 1954, Leach (I971) gives a detailed description of the customary rules based around caste and kinship and their role in creating social boundaries, which perpetuate inter-generational patterns of access to a variety of resources including land and water. He observes that although villagers were acutely sensitive of such issues, no local word exists for the compound groups these systems give rise to. We coin the term 'Purana Complex' (PC) to describe a fundamental unit, which combines discrete social assemblages with defined geographical access, both private and common, to a range of natural resources centred on water. The PC then can be considered as the smallest logical unit within the watershed for interventions that focus on sustainable natural resource management. We go on to consider the less clearly understood relations between such assemblages at the wider watershed level. The PCs as described above, may cover a whole or part of a catchment, depending on its size and hydrological endowment. The size and distribution of tanks can be used to predict their extent. Four and three PCs were identified within the PDW and DDW systems respectively, based around the principal axial tanks in each system (See Table 4).

Despite the far-reaching impacts of economic liberalisation on many aspects of rural livelihood, and a widely held belief that the feudally based caste system is in rapid decline, caste demarcations were observed to remain highly entrenched in the rural areas under study. Although the rigidity with which indigenous village institutions enforce customary rules relating to caste as described by Leach have been relaxed or entirely lost, social taboo on intermarriage continues to be the norm and it is such marital traditions which are most critical to understanding natural resource access and ownership. Within the research areas, marriage usually takes place only within the Purana boundaries or between ancestral communities with whom kinship links are maintained. Consequently, where neighbouring PCs are founded by

[38] There is evidence to suggest that communities with access to a range of radial and axial tanks, alternated cultivation under the more seasonal radial tanks between years according to climatic conditions and labour availability (Ulluwishewa 1992).

different caste groups such differences are likely to be perpetuated. Because of the subtle nature of sub-caste distinctions even within the dominant and most widespread *Govigama* (cultivator) caste, the likelihood of finding parity with neighbouring complexes is low and a hierarchy inevitably becomes established. Such differences may in fact may have come to be based more on kinship that caste *per se*, as villagers typically demonstrate great difficulty in meaningfully categorizing or naming the precise nature of such sub-cast differences[39], different sub-groups even making counter-claims of superiority. Generally however, lower caste groups are more likely to have initiated colonisation around more seasonal base tanks, either radial or those located in upper watershed areas. Because of the pattern of colonisation described above kinship linkages are often greater in a horizontal rather than vertical direction at any level of the cascade. These patterns were particularly marked in the PDW system where lower caste *Kumbara* (potter) communities had settled around several of the most seasonal upper-watershed tanks (see Table 9). Perhaps because of the state of flux in the feudal caste system and the great delicacy with which the subject must be treated, the relevance of the issue to natural resource management appears to have been widely overlooked. This has almost certainly compromised development impact particular with respect to common property resources where great potential for conflict exists as a consequence of poorly informed interventions.

As the issue of caste is a difficult subject to approach directly, cascade level demarcations were most readily assessed by analysing the distribution of hereditary family names. Only 2-3 such names tended to predominate in a single PC. This is somewhat complicated by the fact that many names reflect high or low status, consequently members of lower caste groups, will often change their names to avoid stigma. However whilst discussion of caste issues still requires great sensitivity, upper caste groups tend to be more approachable, who could then be consulted as key informants for triangulation purposes.

Two PCs (DAN and ANK) encompassing 7 tanks are located in the upper DDW cascade. These PCs originate from different ancestral locations. Water management is under two separate FOs and inter-marriage limited due to a subtle distinction within their *Govigama* caste (ANK reportedly being a slightly higher sub-caste). However otherwise relations between the two villages are close to the extent of sharing membership of a single Death Donation Society (DDS). Three DDW farmers also sharecrop lands under Ankendawewa.

Marked caste differences, which exist in the upper PDW and Uriawewa cascades result in a more complex and divisive situation. Farmers from the upper watershed Ihala Diulwewa (IDW) PC and an extended family group managing two radial tanks including Ulpathwewa (adjacent to the PDW PC) are of the low caste *Kumbara* (potter) group. Though sharing common ancestral homes, they colonised the area at different intervals and have little contact with each other. Below these communities are PCs of Pahala Diulwewa and Pahala Sembugama, again both with a different ancestral background and demarcations within the *Govigama* Caste. As a consequence of the close proximity of Ulpathwewa to the PDW PC, they are eligible for membership of village institutions, however other than limited participation in the Death Donation Society, they are essentially marginalised to the periphery of the community. The Pahala Sembugama (SEM) PC lower in the cascade has ancestral linkages with the base tank Paliagama where ownership of the entire command area under Pahala Sembugama tank still resides. These lands are share cropped by family members in the SEM PC. No inter-marriage was recorded between any of these communities, which instead, normally only takes place between ancestral villages on an arrangement basis.

39 The recording of caste credentials and enforcement of associated rules was formerly the responsibility of the *arachi*, a hereditary position held by an influential family in the community.

Table 9. Caste and kinship linkages in selected *Purana Complexes* of three STCs.

PC[1]	Cascade / Tank	Est. Age of PC	Caste[2]	Surname Initials (% Households)[3]				Location and HH membership (%) of principle village institutions [4]				Ancestral village or town
				SN 1	SN 2	SN 3	SN 4	FO		DDS		
Danduwellawe STC												
DAN	DAN1 Mahawewa	>100	*Govi* 2	TM (75)	BM (10)			DDW	94	DDW ANK	100	Tambutegema
ANK	ANK4 Ankendawewa	>100	*Govi* 1	TM (10)	DM (90)			ANK	80	ANK	95	Seyambalagahama
Pahaladiulwewa STC												
IDW	IDW3 Madatuwa	> 70	*Kumbara*	JA (70)	DM (30)			IDW	<20	IDW	82	Waddakarra
IDW	IDW2 Ihala Diulwea	>100	*Kumbara*	JA (45)	RHM (30)	HM (20)		IDW		IDW		W'Karra Kudawwa
PDW	PDW1 Pahala Diulwewa	>200	*Govi* 2	AH M (65)	WB (15)	RM (10)	OS (10)	PDW	75	PDW	85	Tallakallewewa Wadigamanagawa
SEM	SEM1Pahala Sembugama	>200	*Govi* 1	WM (90)				SEM	0	SEM	94	Paliagama
Uria Wewa STC												
NA	PDW6 Ulpathwewa	50	*Kumbara*	JP (90)	JN (10)			PDW	0	PDW	90	Waddakarra
NA	PDW4 Palugas	50	Coolies	RB (100)				PDW	0	PDW	100	Uriawewa

[1] PC = Purana Complex (abbreviation refers to name of principle base tank).
[2] The upper Govi (farmers) Caste is divided into at least 7 subdivisions. The Kumbara (potters) are one of the lowest caste groups.
[3] Initials refer to the first two ancestral names. In formal matters these are given before the adopted name(s).
[4].The FO (farmers organisation) is the most important institution with respect to water management, whilst the Indigenous DDS (Death Donation Society is invariably the most active and inclusive.

13.2 Institutional linkages and access to natural resources

Along with the kinship linkages defined above, membership of the principal village institutions, the Farmers Organisations and the Indigenous Death Donation Societies, help to define the extent of a Purana Complex. The FO is particularly instructive in this respect as ownership of irrigated lands within a PC remains largely within the Purana community and often concentrated in the hands of older farmers residing around the base tank (see section 14.1). Leaseholders and sharecroppers of irrigated lands are also eligible for membership in sharp contrast to the situation found under medium and major irrigation systems. These are most likely to be landless younger farmers from within the PC, though greater external participation is likely to occur under larger tanks lower in the watershed with assured water supplies and higher yield potentials.

Membership of farmer organisations in Ihala Diulwewa and Pahala Sembugama is negligible or non-existent due to their poor access to local irrigation resources. Although such farmers practice fixed (PDW cascade) or shifting (DDW cascade) dry land cultivation, this is normally undertaken on an individual basis. Shifting cultivation takes place on state owned lands regulated by the forestry department.

Death Donation Societies tend to be far more inclusive of the whole village community than FOs (Table 9), are more likely to overlap *Purana* boundaries and to accept outsiders as members. One or more of these institutions may be present in a single village and multiple-membership is not uncommon. Larger and more dynamic societies are likely to attract membership from smaller neighbouring communities often higher in the cascade. Such societies are also likely to meet on a monthly basis, whereas all the FOs except DDW (also meeting on monthly basis) met only once or twice per year to formulate cultivation calendars (*kanna* meetings). No other indigenous institutional linkages were recorded between any of these PCs.

The government offices of the *Govi Sevena Nyamake* (GSN) and the *Grama Niladhari* (GN)[40] are coterminous with the lowest village level or GN administrative divisions, whilst smaller and larger boundaries exist for *Samurdhi* (welfare animators) and health services respectively. GN divisions are likely to incorporate up to 3-4 PCs and Samurdhi divisions 1-3 PCs. The natural pattern of settlement imposed by watershed features has indirectly helped to define these administrative divisions. GN, GSN and Samurdhi officers are typically recruited from, and live within, the communities they serve. Although often appointed through political patronage, they are often well-respected and influential members of local communities, playing a critical role alongside traditional village elders in resolving resource conflicts. Such officers then represent a grass-roots bridge between local communities and the key local institutions that must be mobilised to promote sustainable watershed management through facilitating better co-operation between neighbouring PCs. This is particularly important where social barriers exist in the form of strong caste polarisations.

13.3 Ownership and access to irrigation resources

Tenure of irrigation resources: Three functional patterns of tenure with respect to village tanks were recognised, the patterns being closely linked to the access to irrigated land beneath them:

1. *Tanks managed by community based organisations*: Though formally owned by DAS, all the large tanks investigated (>4.8ha) came under the operational control of village based

[40] Village level administrative (GSN) and agricultural extension officers (GN) linked respectively to the Divisional secretariat and the agrarian services department.

farmer organisations and hence are Common Property Resources (CPRs) used for a wide range of functions by different stakeholder groups, with different ranges of excludability for the various functions. Individual households freehold, leasehold or sharecrop demarcated irrigated plots under the tanks, under the terms of the 1959 Paddy Lands Act (see working paper SL1.1) and it is these farmers who have greatest control over the principal consumptive use of water for irrigation.

2. *Temple tanks:* A residual area of a once extensive estate in the PDW upper watershed remains the property of an ancient temple. Several small, mostly highly seasonal tanks are located on this land (see Table 4). Only tanks belonging to religious orders can be formally privately owned. However, they are effectively used as CPRs by the adjacent villages with the traditional acquiescence of the temple. Lands under the tank are leased out by the temple, but are neglected due to lack of access to state funds for tank rehabilitation. Cropping intensities under these tanks are very low (see section 10) and leaseholds are erratic, due to the low yields and high risk generally associated with their cultivation. Also temples frequently lease such lands to farmers, often members of their own family, outside the local community.

3. *Small 'privately' owned tanks*: Although still technically owned by the state, many of the smallest radial and highly seasonal tanks are effectively owned and operated by individual families or extended family groups, who were responsible for reclaiming them from the jungle over recent decades.

Ownership and access issues are therefore more complex in the PDW system, which shares all three forms of access patterns. In DDW where most of the radial tanks have been abandoned for cultivation over recent years[41], only the first form currently exists.

Internal and external access patterns: Access to irrigated lands under village tanks often extends beyond village boundaries, principally as a result of out-marriage and kinship linkages (see section 13.1), conversely many farmers under village tanks have access to irrigated lands under nearby perennial tanks with assured water supplies. Such extended access patterns have consequences for the integrated management of water. Where user groups for different water-use functions are separated into geographically discrete areas, there is less likelihood of these groups sharing the same use patterns and priorities, potential for resource use conflicts are therefore often increased[42]. The internal and external patterns of access are considered in the following sections, after which an attempt is made to classify the conflicts that can arise from these patterns.

[41] Although many smaller tanks exist in a perpetual cycle of abandonment and rehabilitation, it would appear that many of the large number of tanks brought back into use in the 1950s and 1960s have enjoyed a relatively short period of use. Improved quantification of these historic rehabilitation patterns is the subject of ongoing research.

[42] i.e. conflicts are likely to occur where a group non-adjacent to a tank use it only for irrigation purposes, whilst another group living in close proximity have only bathing access (see section 14).

1. *Internal access to irrigation resources within PCs.*

Table 10. Paddy land holdings (acres) by household in DDW and PDW STCs.

Tank	Household frequency of local paddy holdings (ac)[1]				Mean area (acres)	External access (HH)[2]	W/O access irrigated land (%)[5]
	0	<¼	<½	<2			
DDW STC							
Danduwellawe	7	12	8	22	0.5	3 [10][3]	22
Mahagalkadawala	-	-	-	-	1.5-2	-	-
PDW STC							
Ihala Diulwewa	-	-	-	-	1.6	-	-
Pahala Sembugama	-	-	-	-	0.7	-	-
Palugaswewa	-	-	-	-	1.5	-	-
PDW	6	24	8	11	0.5	12 [20][4]	11.5
Paliagama	-	-	-	-	1 – 2	-	-
Uriawewa	-	-	-	-	2	-	-

[1] Frequencies available only for DDW and PDW villages where detailed RRAs were undertaken.
[2] No of households with access to lands under local major irrigation systems [% of total households].
[3] 3 Households with lands in the Rajangane scheme
[4] 6 Households with lands in the Inginimitya scheme &6 with lands in the Uriawewa &Ravi Benda Ela anicut schemes
[5] Farmers with no internal or external access to irrigation resources.
Note: 1 hectare = 2.47 acres.

Table 10 shows average irrigated land holdings under selected tanks. Thirty-eight and forty-six percent of farmers under DDW and PDW respectively farm less than 0.25ac of paddy land whilst 22 and 11.5% of farmers have no access to irrigated lands under the village tank(s) whatsoever. Demographic changes have been accompanied by a trend of increasing land fragmentation. This impacts most heavily on younger farmers, depriving them of access to productive resources. Such change has also increased numbers involved in decision-making, contributing to the decline of the collective *'bethma'* cultivation system. For poorer farmers with limited or no access to irrigated lands, exploitation of other natural resources becomes an important source of income. This includes manual labour in quarries, which are mainly located in upper watershed areas, logging[43], livestock grazing on CPRs, hunting and subsistence fishing. Enhancing tank fisheries may provide an alternative livelihood option for those engaged in other, more destructive, natural resource exploitation.

2. Access to irrigation resources between neighbouring PCs within the watershed:
Formal and informal access arrangements also exist between villages within STCs taking two principle forms, which tend to operate in opposite directions within the watershed.

- Farmers from upper watershed villages are most likely to lease land with more reliable water availability lower down the watershed[44]. However, often only the least fertile areas are generally available under these arrangements.
- Land ownership under seasonal tanks in upper watersheds and hence control of water management, often resides with older members of kinship groups in lower watershed areas due to the chronology of colonisation (see section 14.1). Where local access to water resources is restricted in this manner, opportunities for enhanced fisheries management are constrained.

[43] The lack of natural forest resources around the PDW cascade means this is an important livelihood activity only in the DDW system.
[44] Such farmers pay ¼ of their crop to land owners in return for use of the land or ½ of the crop under an arrangement where the landowner also supplies seed, fertiliser and pesticide inputs.

3. External access to irrigation resources out-with the watershed:
Whereas 20% of households in PDW village had access to leased lands with assured water supplies under nearby major irrigation systems only 10% had similar access in DDW village (the livelihood implications of such disparities are the subject of on-going research). This is probably a consequence of the more local proximity in the first instance. In addition to such informal 'lease-holdings' older farmers in other villages were reported to have received grants of lands under nearby major irrigation schemes rehabilitated in the recent past. These farmers will typically only invest labour in the preparation of lands under seasonal tanks after labour commitments for land preparation under perennial systems have been met. Alternatively, their seasonal lands are often leased or sharecropped by other local farmers.

Other families gain access to external irrigation resources both large and small-scale through intermarriage between related communities. Females rather than males are more likely to leave the village when they marry. Though subordinate to males in terms of land inheritance, women typically do receive a share of parental lands albeit smaller than male shares. More often than not, this land is retained rather than sold when they leave the village. Sometimes this is leased or sharecropped within the local community, though it is also common for couples to migrate back to the ancestral village for short periods to prepare and harvest their lands. This trend increases the likelihood of absentee external involvement in local cultivation and water management.

13.4 Conflicts arising from Community Based Natural Resource Management

The geographical separation of watershed areas into discrete PCs and the patterns of internal and external resource ownership / management and the relative disparities which then arise, can result in many forms of conflict in CBNRM. Grimble and Wellard (1997) categorise such conflicts as occurring at the micro-micro level (within community groups) and the micro-macro level (between community groups and outside organisations). Warner and Jones (1998) further subdivide micro-level conflicts into intra micro-micro conflicts (within the group directly involved) and inter micro-micro level conflicts (between those directly and indirectly involved). In the current context, the resulting categories broadly correspond to 3 levels of geographical organisation: within and across PC boundaries at the intra and inter micro-micro levels respectively and across watershed boundaries at the macro-micro level. Following are some of the major natural resource conflicts identified at these levels:

1. Intra micro-micro (internal PC boundary) conflicts:

- *Intergenerational conflicts:* Whilst younger villagers around seasonal tanks denied access to productive resources often feel disenfranchised, older farmers in the base community accuse them of sloth, particularly when younger farmers neglect agriculture in favour of the low status activity of fishing. Such conflicts are often reflected in the membership of village institutions including DDSs and FOs.
- *Breaking of CPR operational rules:* Disenfranchised youth poorly represented by farmer organisations are most likely to ignore seasonal bans on fishing and restrictions on grazing and exploitation of forests in catchment areas. Such activities are often well tolerated at low level, however development interventions that ignore such groups and in the process impede their hitherto free-access to these resources have potential to exacerbate latent conflicts, particularly with respect to exploitation of fisheries resources (see Box 7).
- *Contradictory natural resource needs:*
  Breaking of operational rules as described above can also result in conflicts between local livelihood and wildlife needs as habitats are degraded. In DDW such conflicts currently help define the limit of upper watershed colonisation due to the presence of marauding wild animals, especially elephants and wild boar.
  During the dry season the moist grassland of tank beds provides one of the main grazing grounds for ruminant livestock. In many villages a division tends to exist between poorer

farmers who are more likely to be smallholders of livestock and wealthier paddy farmers. Livestock grazing is extended to the rear of the tank during the cultivation season when alternative pasture availability is low due to agricultural requirements[45]. Conflicts occur when poorly tended animals escape into the adjacent command areas of upper tanks, which have become progressively continuous with lower tanks as catchments are cleared. A proposal which aimed to enhance both livestock and fisheries production through community-managed pasture improvements schemes (or the placement of other cattle attractants such as urea licks) to the rear of tanks, received a mixed response. Many felt this could potentially enhance existing conflicts between small-scale livestock holders and agriculturalists.

- *Capture of natural resource projects by elites:* Many farmers with poor access to irrigated land will often have no formal membership of farmer organisations through which development initiatives facilitated by outside agencies are often routed.
- *Political conflicts:* Communal patronage politics that offer short-term gain, run counter to the interests of longer-term sustainable development. Due to the relative isolation of different PCs, this has greatest impact through polarisation and internal division of kinship groups. Such division is most evident amongst larger communities.

2. Inter micro-micro (trans PC boundary) conflicts:

As previously indicated although some overlap exists, fishing and livestock-grazing activities tends to be restricted to the land areas encompassed within individual Purana Complexes and the ownership of irrigated land follows a similar pattern. During the dry season, farmers in upper watersheds are likely to exploit larger perennial tanks lower in the catchment along with adjacent lands, for bathing and livestock watering and grazing purposes. This is generally well tolerated during periods of low water availability, falling as they do, out-with the main cultivations seasons when livestock related conflicts are most likely to arise. Such conflicts as were observed were therefore more marked within Purana Complexes. This is perhaps a consequence of both geographical separation and the fear of potentially more severe sanctions being taken outside the boundaries of immediate kinship groups.

Of the micro-micro conflicts identified above, those relating to the breaking of CPR operational rules are most likely to extend over Purana boundaries, particularly with respect to the ‘poaching’ of tank fisheries. However, perhaps the greatest conflict arising at the trans-boundary level is the lack of cooperation that often exists between neighbouring communities and the negative repercussions that this has on integrated watershed management. Often with less visible linkages against a background of highly erratic seasonal rainfall, such trans-boundary conflicts (i.e. potentially through over-application of agro-chemicals[46] or hydrologically uncoordinated tank rehabilitation) also tend to be the most poorly perceived by local communities.

3. Micro-macro (trans-watershed boundary) conflicts:

Environmental conflicts:

Industrial scale quarrying at the top of the Danduwellawe system sponsored by local businessmen was welcomed by DDW villagers at the head of the system as it brought assured employment opportunities. However intensification of this activity has resulted in extensive degradation of metalled access roads with widespread impact on many adjacent communities

[45] Only 14% of farmers in both villages owned livestock including cattle, buffalo or goats. Most of these livestock holders are small holders owning only 2-15 head of cattle and most belong to the lowest wealth rank with poor access to irrigable land. These farmers adopt and extensive production strategy using low yielding but drought resistant varieties. These are well adopted to seasonal fodder and grazing shortages, but have very low milk yields normally sufficient only for occasional family consumption. Farmers instead hold cattle as liquid assets for emergency sales during the dry season or time of family illness. Many stocks are held on share basis with local Muslim communities who receive a 50% share of all offspring. One affluent farmer in PDW had over 60 cattle under semi-intensive production for commercial dairying with support of local line agencies.

[46] Although some evidence relating to pesticide accumulation in larger institutionally managed systems exists (section 12), no research was identified as having yet been undertaken within the seasonal/village tank context.

and more seriously in the longer term, has also been attributed with the diversion of an aquifer that formerly issued into Mahawewa tank of DDW village long after the rainy season.

In DDW conflicts between external commercial logging interests exploiting upper catchment forests and local communities. Much of this forest now consists of secondary scrub forest of low commercial value. Other areas have been replaced with eucalyptus plantations with negative impacts on ground water recharge and forest bio-diversity. The resultant catchment erosion is increased further by the practice of shifting cultivation with insufficient fallow periods to maintain soil fertility. The situation is compounded by the unclear legal and political situation that surrounds access to these government lands with access often determined according to political patronage. This is in sharp contrast to the legislation formulated to protect communal rights to irrigated lands under village tanks.

Other conflicts at this level include disputes arising as a consequence of differences between the aspirations of community groups and the expectations of NGOs, their outside sponsors and local and national government line agencies. These are more difficult areas to assess and require further research.

Warner and Phillips suggest that a detailed Conflict Management Assessment (CMA) should be undertaken as a component of traditional situation analyses, which consider CBNRM. The following sequence of questions can be used determine suitable intervention outcomes:

1. If the conflict is likely to overwhelm existing, customary, institutional and legal approaches to conflict management it may be appropriate to try and strengthen these.
2. If the conflict is left alone will new management mechanisms organically materialise within an acceptable time frame?
3. Will the long-term benefits of allowing the conflict to transform itself into a positive force for social reform outweigh the short-term costs?

The above analysis suggests that there is great potential for initiating or enhancing latent conflicts where interventions are restricted to conventional approaches relying on stocking of larger individual village tanks with hatchery-produced fish. Such approaches should be complemented by innovative approaches based around the low input enhancement of existing resource systems, which might build on the residuum of traditional systems of community management. Such an approach is consistent with an objective proposed for priority adoption at a recent DFID workshop committed to supporting sustainable livelihoods:

- *"To build institutional capacity that empowers the poor, with an emphasis on securing rights of access to and mitigating conflicts over water resources"* (Soussan 1998).

14 Farmer priorities for use of small tank water resources.

Farmers in Pahala Diulwewa and Danduwellawe were asked to identify and rank the importance of different uses of village tank resources most accessible to them. Similar criteria were identified in both villages, these included: irrigation, bathing, domestic uses (clothes washing and toilet purposes), livestock watering, fishing and a range of micro-industrial uses (brick making, cajun thatch retting and pottery making). Some of these uses related directly to water, some to the fabric of the tanks (i.e. brick making, grazing) and some related to both the fabric and the water (i.e. bathing and livestock).

No one reported using tank water for consumption purposes nor was this ever observed. The results of ranking and scoring exercises were analysed using Friedman's test (a non-parametric analysis of variance) that revealed significant concurrence between farmers for water use priorities. Results are presented in Appendix 6, and details of the data collection and statistical methodology in Working Paper SL1.1.

In both villages irrigation and bathing ranked significantly higher than other uses ($P < 0.05$). Whereas the primacy of irrigation (see section 15.1) was to be expected, the high priority accorded to bathing was more surprising and arose as a consequence of several factors. Firstly decreasing productivity of land linked to land fragmentation and decreasing soil fertility, has reduced the relative importance of irrigation to many households, whilst ‘loss’ of pasture has contributed to reductions in livestock holdings. Bathing by contrast remains an important daily social event within the local culture. Even those now working off-farm are likely to congregate around the tank in the evening to bathe, meet friends and exchange news. In Danduwellawe, many of the poorest farmers who had no access to irrigated land and worked in nearby quarries ranked bathing as their highest priority. During a community meeting in DDW a proposal was made as to whether soap inputs (*vis a vis* reducing off-flavours associated with seasonal tank fish production - see below) and potentially the transmission of certain waterborne diseases could be reduced through improved provision of alternative bathing facilities. This was met with an almost universally negative response. In fact the village is already relatively well served with agro-wells and hand pumps, which are barely used in this respect, most villagers preferring to travel up to several kilometres to larger nearby tanks during the dry season, underlining the strength of the social custom centered upon communal tank bathing, which generally involves complete immersion. Throughout the study, bathing was found to be the most universal common property function of village tanks giving practically the whole community a stake at least in the larger PC base tank, regardless of wealth and access to alternative private water resources.

Of the remaining uses, livestock watering was ranked higher in PDW reflecting higher levels of livestock holdings (see working paper 5). In both villages one of the greatest ambitions of many farmers was to build their own permanent house, for which they would progressively collect materials as funds and time allowed. To this end many farmers also valued the ancillary use of water for brick production, for which the local red soils are ideally suited. Fish production ranks as lower and middle level use in PDW and DDW respectively. This reflects the availability of low cost commercial fish available in the villages (Working Paper SL1.4), whilst the relative difference may be a result of the higher caste and wealth status in PDW village. Despite the low priority given to fishing, significant complementarities and externalities can be expected to arise from the priority accorded to bathing. Most villages try to maintain a residual amount of bathing water for as long as possible into the dry season, which may otherwise have been pumped out for emergency irrigation. This is highly complementary with fish production, extending the growing period and or providing refuge for breeding populations over this difficult period. However it also brings potentially negative consequences in terms of access restrictions designed to conserve water quality for bathing (limiting potential for staggered harvesting options) and soapy off-flavours imparted to fish stock affect their commercial value. Although such off-flavours are largely confined to the dry season, this is the period when most harvesting takes place and negative consumer perceptions are also associated with the darker colour of these fish relative to perennial tank stocks.

In addition to uses of water identified above, other physical attributes of the tank also bring benefits to the community, which were not considered in the above analysis. These include the provision of pasture for livestock during drawdown episodes when other grazing resources are scarce, the excavation of clay and sand deposited on the tank bed, used for construction purposes and for recharge of ground-water resources exploited by agro and tube wells (Table 11). This combination of uses is common throughout Asia, however the priority accorded to bathing which fulfills an important social as well as hygiene function are extreme in the Sri Lankan context and this has important consequences for trade-offs between alternative uses.

Table 11. Distinguishing between, uses of stored water and uses of physical infrastructure incorporated in village tanks.

Resource use	Natural capital: Stored rain water	Physical capital Tank infrastructure
Irrigation & drainage		
- Irrigation	- Distribution to command area [Principle consumer] - Seepage to adjacent home garden areas	- [Drawdown v dead storage]
- Silt harvesting		- Trapped silt – formally used as field fertiliser.
- Flood protection		- Prevents damage to soils and physical infrastructure
Domestic uses		
-Bathing & washing clothes	- *In-situ* [quality modifier]	- Bund steps facilitate access
…- Toilet, dish washing	- *Ex-situ* Home use	
…- Drinking	- *Ex-situ* Groundwater recharge	- Agro & tube wells below bund
- Vehicle washing (bikes, vans, tractors)	- *In-situ* [quality modifier]	- Roads built across bunds facilitate access
Livestock		
- Watering	- In littoral areas	
- Grazing		- Tank bed: rainy and dry season - Command area: dry season
Biomass gathering		
- Fisheries	- [Indirect quality modifier]	- [Trophic status & productivity]
- Wild game	- Dry season watering	- Hides constructed around water
- Aquatic plants		- Macrophytes in littoral areas, tubers from tank beds.
Micro-industries		
- Brick / pottery making	- For fabrication	- Excavation of clay kilns ranged around tank bed[1]
- Cajun retting	- [Quality modifier]	- Residual dry-season storage
- Construction	- Water for cement/mud	- Sand and gravel extraction
- Illicit distilling	- [Quality modifier]	- Stills located in immediate catchment[1]
Environmental		
…Habitat		Direct and indirect provision of habitats for a wide range aquatic terrestrial, and avian fauna

Note: Impacts are distinguished from uses by square brackets [ ].
[1] Location of these functions is determined by proximity to water resources in the tank and fuel wood resources in adjacent catchment areas.

Further research aimed at improved understanding of the priorities attached to these various uses by communities facing different seasonality constraints is required. From a fisheries production perspective, staggered harvesting options could fill a demand gap that persists for several months after the *maha* rains (December – March)[47], in combination with early stocking and the use of gillnets, formally not available to this fishery. In addition to increasing net productivity it could also reduce the potential for muddy/soapy off-flavours associated with harvests from residual dry-season water storage (Working Paper SL1.4). However,

[47] When production from perennial reservoirs falls to a seasonal low

preliminary research suggests such options would be unpopular with the majority of villagers who rely on the water supply primarily for bathing/domestic uses and irrigation. In this context, management strategies that focus on alleviating the conflicts that currently exist between fishermen and other water-users are likely to be most relevant (section 13.4). Such strategies are likely to adhere more to traditional collective harvesting strategies that concentrate intensive fishing activities into the shortest time-spans during the dry season.

14.1 Irrigation and water management

Farmer Organisations: The cultivation calendar including the types of crops to be cultivated, the sequence of irrigation releases and maintenance issues are decided at a '*Kana*' (cultivation) meeting usually held around one month before the main rains. Cultivation normally begins only when a threshold amount of water has been collected in the tank, typically 50% capacity by mid-December at the latest, and cropping intensity is likely to be reduced or entirely abandoned if rainfall is poor. This eventuality is most likely around more seasonal tanks, where irrigation is 'supplementary' to direct rainfall and in most years rice production is a doubtful strategy. Successively poor rainfall years serve to re-enforce risk aversion and hence threshold criteria for initiating cultivation. This has resulted in an increasing trend to a single inter-seasonal cultivation falling between the traditional *maha* and *yala* seasons. Although increasing frequency of drought is likely to worsen this situation, such irregular cropping patterns are not new. In his book 'A village in the Jungle, Lionel Woolf (1913) documents how irrigated production under a seasonal tank in Southern Province, took place as little as once in 8 years around frequent drought episodes. This trend results in surplus storage water in seasonal tanks remaining unused for irrigation during many years. Alternative management strategies that recognise the multiple use/user characteristics of water, including fisheries, should be devised to better utilise this surplus capacity.

The effectiveness of farmer organisations in implementing water management decisions varied between villages. Both DDW and PDW, FO's had been recently strengthened with NGO assistance and the DDW organisation was particularly active as a consequence. This organisation also had a more inclusive membership than DDW despite there being a larger proportion of families without direct access to irrigation resources. This was attributed to the smaller size of the village and it's greater cohesiveness, in part fostered by the participatory nature of recent integrated development initiatives (section 11). Physical improvements were also accompanied by enhanced collective water management practices, designed to improve irrigation efficiency (see Box 5.). Farmers were very positive about these improvements reporting that water disputes had decreased as a consequence. Although the DDW situation was an example of best practice within the confines of this study, even here such management practiced focused predominantly on water within the farm subsystem (i.e. use of residual soil moisture and reduction in conveyancing losses – Box 5). Few examples were found in any villages of collective management practices, which aimed to conserve storage capacity, particularly with respect to maintenance of catchment cover. Limited clearance of aquatic weeds was reported in Ankendawewa, though more with a view to maintaining open water for bathing. Farmers in DDW agreed to utilise waters from the smaller of the two tanks (that together supply the village command area) first, the smaller/shallower Bundapuwewa being more prone to evaporation and seepage than Mahawewa (Table 5).

In contrast to DDW the FO under Mahagalkadawala, the perennial base tank of the DDW cascade, had effectively ceased to function. Until recently management here was under the traditional *Velvidane* system. However the *Velvidane* had recently abandoned his position after failing to receiving the traditional levy, a small proportion of all rice yields. Here, asynchronous field preparations and sowing had taken place over a month, compared to only 14 days in DDW, both long and short rice varieties had been planted and water issues were made on an *ad hoc,* often individual basis with unnecessary frequency. All of these factors, reflective of poor collective management, reduce the efficiency of water use through a combination of unnecessary conveyance losses and poor utilisation of rainfed soil moisture. Some best-practice recommendations based on field observations are shown in Box 5.

Box 5. Collective irrigation management practices and water conservation in DDW village.

Following is a range of techniques employed by farmer organisations to improve irrigation efficiency (i.e. the percentage of water actually consumed by growing plants).

1. Use of residual soil moisture:

- Synchronised field preparation and crop sowing, timed to take place after a spell of heavy rain conserves water stored in the village tank for future use.
- Supplementary irrigation: Under more seasonal tanks, releases are made only when direct rainfall is insufficient to sustain plant growth. This can be contrasted with regular scheduled releases, which are the norm under perennial systems.

2. Minimising conveyancing losses: Field distribution systems under rain fed systems are typically unlined and subject to high seepage losses.

- *Synchronised cultivation calendars:* Losses are significantly reduced where a collective decision is taken by farmers to adhere to the same cultivation calendar. This includes use of cultivars of the same duration, which together with synchronised field preparation permits fewer; larger irrigation releases to be employed at regular intervals rather than many smaller releases taking place on an individual basis. Commercially available hi-input rice cultivars typically range from 3.5 -4 months. Some lower yielding local varieties require as little as 2.5 months to mature which are occasionally grown under rain fed conditions without even supplementary irrigation.
- *The bethma system*: Under the *bethma* system cropping intensity is reduced during the *yala* season. These lands are likely to be located in the highest areas of the command area in order to minimise conveyancing losses (reported in PDW only).

Most of the other FO's investigated were also very weak, meeting infrequently, with activities rarely extending beyond basic system maintenance and a single meeting to plan the *maha* season calendar. As these are the principle institutions responsible for coordinating the management of water, such lack of institutional capacity is identified as major constraint to the successful integration of aquaculture in community-managed tanks.

Water issue frequency and yield potential: Irrigation patterns showed a progressive tendency towards supplementary irrigation with movement up both cascade systems. Farmers under Ulpathwewa and Danduwellawe (upper watershed) would only obtain 2-3 releases from their small tanks. This increased to 5-6 issues under PDW tank (mid watershed). Farmers under Uriawewa (the PDW base system tank) receive 10 or more issues per cultivation season, whilst *ad hoc* irrigation takes place under Mahagalkadawala due to the weak institutional situation described above. Mean yields are therefore lower and risk of crop failure greater in upper watershed command areas as reflected in the generally lower CI's reported by farmers under these tanks.

In years with good rains farmers in DDW and PDW reported yields between 850 to 1,100 kg paddy per acre (2100 to 2700 kg/ha). These averages compare well with figures presented by Abeyratne (1990), who reported an average yield of 836kg/ac (2065 kg/ha) under minor irrigation compared to 1,230 kg/ac (3040 kg/ha) under major irrigation schemes. Risk avoidance and this difference in yield potential is a major incentive for many farmers to lease extra land (an illegitimate practice[48]), sharecrop or labour on lands under neighbouring major systems as alternative strategies (section 14).

[48] These laws were enacted to reduce the likelihood re-sale and fragmentation of newly settled plots, allocated under recent major irrigation developments.

Yala cultivation (April-May): Most farmers under seasonal and semi-seasonal tanks reported having almost abandoned *yala* cultivation. Reasons cited were reduced water availability and competition for water, decreasing soil fertility, land fragmentation and institutional weakness of CBOs. These factors have combined to reduce the useful productivity of land and progressive abandonment of the *bethma* system[49], which is a traditional strategy for reducing risk by such communities.

Maha cultivation (Nov- March): At the time of study; the end of December, the *maha* rains of the main growing season were a month overdue. Farmers in DDW were the last in the watershed to prepare their fields due to the higher risk of water shortage and crop failure in the upper catchment. The farmers finally began preparation of the whole command area with the tank less than half full, gambling on additional future rainfall. Farmers in PDW were less willing to accept this risk and had decided to wait for further rains or abandon the *maha* season paddy production entirely if the rains did not come. A greater proportion of farmers from this village had options for cultivation or labour under a variety of local irrigation systems with assured water supplies. When a week after planting under DDW, no further rains arrived, many farmers were beginning to consider abandoning the paddy, preferring to retain water for bathing purposes later in the year. Fortunately rains came shortly thereafter.

Whilst there were no reports of *bethma* practice during the *maha* season, farmers in PDW had attempted to cultivate OFCs during recent *yala* seasons. These crops, which include: chillies, pumpkins, gherkins, green gram and groundnut, consume less water than paddy. However, because of the perishable nature of many of these crops and poor terms of trade available to small producers, many farmers had since discontinued such production in favour of subsistence paddy cultivation.[50] Furthermore, without exception, paddy farmers in all the villages investigated practiced wet seed broadcasting rather than transplantation. Although broadcasting consumes considerably more water than the transplantation method, it is increasingly adopted because of its lower labour requirements set against the current historically low commercial value of rice. Therefore, although water availability is often cited as the single greatest constraints faced by farmers in sustaining their livelihoods in these rainfed areas, they continue to eschew less water consumptive cultivation practices, particularly when low labour input cultivation strategies can be readily be practiced under the many recently developed major irrigation schemes with assured water supplies in the area (see Fig 1)

These observations have positive and negative implications with respect to the technical potential for aquaculture and it's ability to benefit the poor. Sakthivadivel (pers. comm.) reported that on average in Kurunegala, farmers farm 80-90% of the tank command area during *maha* and only 20-30% in the drier *yala* period. Consequently many tanks retain dry season water, which is no longer used for irrigation. This could extend the seasonal window for aquaculture production. However, our own work has shown such availability to be highly erratic. Whereas in years with delayed rains cultivation maybe abandoned resulting in extended water storage, equally promising rains may be followed by drought. In such instances, farmers under DDW and PDW tanks will pump dead-storage water below the minimum drawdown imposed by the sluice, for emergency irrigation compromising fish production. In this context of unpredictable water availability, conflicting water requirements and the low priority awarded to seasonal tank fisheries, flexible, low cost, low-input-output systems are likely to offer greatest potential for diversifying and sustaining the livelihoods of the poorest groups.

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[49] This is a system whereby freehold rights are withheld during the dryer cultivation (or drought) season and a reduced area of irrigable command is divided amongst all landed farmers (see working paper 5).
[50] By contrast to OFCs rice is relatively resistant to insect attack and can be stored for up to 2 years in traditional storage systems.

15 The current status of fisheries management

Fish production in STCs appears to be of greater importance to the livelihoods of villagers in the lowest wealth ranks relative to those in middle and upper ranks. This is attributable to several factors. Most of the fish consumed in both cascade systems originates from large local perennial reservoirs, yielding a cheap, highly available product delivered fresh on a door-to-door basis by mobile 2-wheeler vendors (Working Paper SL1.4). By contrast, very little of the production from seasonal tanks enters commercial markets, due to negative consumer quality perceptions associated with such fish. Most is used instead for local household consumption. In the current study only Uriawewa, a medium-size irrigation tank supported a small (12 canoes) full-time artisanal fishing community, whilst poorer, often lower caste communities in upper-watershed areas rely most heavily on subsistence fisheries strategies. Most respondents around the high caste village of PWD said they would not catch fish themselves and only consume fish from their village tanks if they were gifted or purchased from the smaller number of villagers that do fish regularly (5-6 individuals). By contrast, a group of 25 male youth from the lower caste upper watershed village of Ihala Diulwewa participate regularly in both sanctioned and unsanctioned fishing activity in a large number of tanks up to 6km away from their own village with it's modest water resource. Fig 7 is a fishing mobility chart that graphically illustrates this relative dependence of lower caste/upper watershed groups on seasonal tank fisheries within a wide radius of their home village.

Traditional communal fishing practices and taboos formally designed to both restrict access and preserve stocks have become eroded along with the community-based institutions that contributed to their enforcement. They endure in part only as a consequence of the priority accorded to bathing rather than fishing. Direct efforts to enhance or manage the fisheries in any of the tanks investigated were restricted to very occasional individually sponsored movements of wild broodstock described in section 11. Only two fishing organizations, both initiated by external institutions, were recorded and have so far proved largely ineffectual (see Box 7). Consequently, with the exception of Uriawewa all the fisheries are casually exploited by a small number of farmers in the tank locality with degeneration to full open-access status curtailed only by a residuum of weakly enforceable customary rules and norms favouring other priority uses. Most fishing effort takes place during the drier months (June – July). More individuals participated in the fishery in DDW than PDW, perhaps reflecting the lower wealth status of this village (Working Paper 5). In Ankendawewa and Rathmalewewa no objection was raised to neighbouring villagers catching fish, when they were part of the same kinship groups and they observed bathing related access rules.

The major common rule relating to seasonal tank fisheries is a prohibition on gill, seine or cast-net fishing (i.e. involving entry into the tank) during the dry season (usually 2-4 months between May to September) to preserve the quality of any residual water for bathing. This was the case in all the semi-seasonal, seasonal and highly seasonal tanks investigated (see Tables 5 and 6). Occasionally the village FO formally enforces these bans, though more commonly there is simply informal customary agreement of adjacent communities who rely on the resource for bathing, with no formal means of enforcement. A secondary bathing related ban may also be imposed between March to April prior to the onset of the SW monsoon depending on water availability after the *maha* cultivation season. A further common perception relates to the acceleration of percolation losses as a result of fishermen walking on the tank bed, resulting in the occasional imposition of additional fishing bans during cultivation seasons. Instances of conflict caused by external fishermen or 'poachers' flouting such bans are very common. Communal harvesting, which usually takes over 2-3 days when tanks are reaching their lowest water-spread, is often prompted on an *ad hoc* basis by an increase in unsanctioned poaching activity stimulated by the ease with fish can be caught at this time.

A variety of selective and non-selective fishing methods were observed. Gill netting (mostly 2"stretched mesh size) is the most common method. These are widely available, relatively cheap and can be used through much of the year, in addition to the final harvest. Gears are also often borrowed from neighbouring villages, or the same outsiders invited in to participate in the intensive fishing that takes place during the collective harvest. Whilst a range of gear sizes are fished in larger tanks only smaller gillnets (stretched mesh sizes of 2" or less) are used in the more seasonal radial tanks, reflecting the small windows available for fish growth in these water bodies.

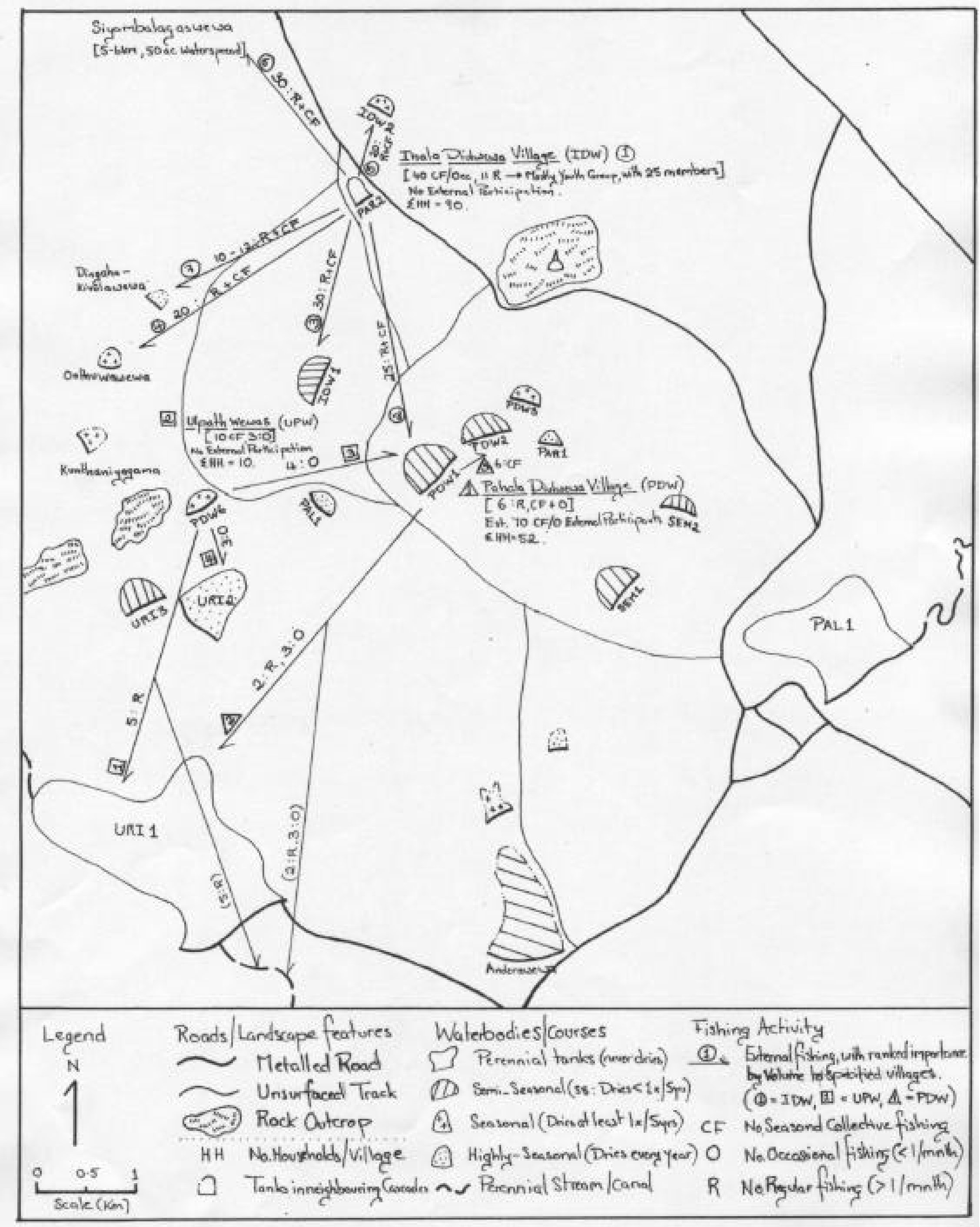
Passive fishing is rare, with the exception of the collective harvesting period when rows of gill nets may be left *in-situ* and rechecked over a number of days. This is attributed to the risk of leaving valuable gears unattended which are then liable to destruction or confiscation where fishing activity is unsanctioned[51]. Whereas a few villages had access to seine nets, others reportedly discouraged their use to conserve smaller stocks for recruitment in subsequent years where sufficient storage remained in the tank. Younger children often use hook and line for recreational purposes, whilst subsistence fishermen also resort to their use during periods when other gears are less efficient (i.e. periods of higher waterspread, or aquatic weed encroachment) or banned. This form of fishing is generally well tolerated by other water users for two reasons. Firstly catch per unit effort is relatively low and most villagers are generally sympathetic to small-scale fishing activity for subsistence purposes. Secondly, this form of fishing usually takes place from the bund avoiding conflicts with bathers or irrigators.

Whereas communities around semi-seasonal or perennial tanks in mid-watershed areas demonstrated relatively low tolerance to participation of upper watershed villagers, the situation was found to be more relaxed in the larger Uria Wewa tank. Here artisanal fishing by local fishermen (members of the new co-operative see Box 7) is canoe based and these fishermen expressed little objection to the shore based, small-scale fishing activities of 'outsiders' regardless of their type of gear. In the smaller Mahagalkadawewa, few local villagers take an interest in the fishery but allow participants higher in the watershed to participate in regular and seasonal fishing, sometimes in return for a levy on their catch!

In DDW, many farmers used traditional wicker 'karaka' traps. Used in shallow water during the dry season, this device is shaped like an inverted funnel; trapped fish are removed through a hole at the apex. This trap allows fishermen to be highly selective and is mostly used to capture larger *static* predatory species, especially snakehead, in very shallow water (< 0.75m). Limited use is also made of cast nets, though these are expensive and less commonly available.

[51] Several instances were reported of farmers destroying 'passive gillnets' being fished by participants from Ihala Diulwewa (i.e. out-with the PWD Purana Complex).

Figure 7. Fishing mobility chart showing the relative importance of seasonal tank fisheries to low and high caste communities, in Ihala Diulwewa and Pahala Diulwewa/ Ulpathwewa villages of PDW cascade (See Table 4 for key to tank identification codes).



Negligible fishing activity takes place during the earlier part of the *maha* rainy season as few larger fish remain after the communal harvest. As tanks reach their maximal water spread (Dec – Jan) fish begin to migrate up the cascade systems to feed and/or breed in recently submerged and highly productive littoral areas. Although a potentially destructive practice, the ease with which such fish can be caught attracts some of the earliest fishers of the season. Activity then increases as water-levels fall following irrigation releases, slowing or stopping again as bans are imposed at threshold water levels for bathing, or when the tanks begin filling again during the secondary *yala* cultivation season. These fishing patterns and choice of gears mean that large volumes of snakehead (bottom dwellers relatively immune to the gill net fishery) tend to be caught during the communal harvest period, whilst more sustained tilapia production takes place through earlier months of the year.

Wide variation in harvest size, yield and seasonal gluts have been recognised as major constraints in seasonal tank culture fisheries. Staggered harvesting systems can increase net production, reduce seasonal gluts and decrease the size range of harvested fish. This is achieved by selectively fishing for larger fish allowing slower individuals to accelerate their growth. With existing fishing patterns relying mainly on size-selective gill nets, *de facto* farmers already practice staggered harvesting, though potential impact is probably lessened by the small size of nets employed in upper watershed tanks (1-2" stretched mesh) sometimes employed in a seine like fashion.

Staggered options also require increased fishing effort when water spreads are greater earlier in the season. Further research effort is required to assess whether farmers would consider this as a valuable of use of limited labour resources.

During spate conditions groups of farmers were observed harvesting large numbers of migrating fingerlings from spill waters within the PDW cascade. These were windfall catches harvested on an impromptu basis with ready to hand materials including mosquito nets and plastic bags and the catch used for immediate household consumption, often fried as so-called 'bites' to be consumed with beer. More organised exploitation of spillways under major irrigation systems (Rajangane and Inginimitya) with higher volume and longer duration spill events and a wider range of fish sizes, is undertaken by casual and artisanal fishermen using a variety of gears including gill and cast nets.

Spill catches observed low in the PDW cascade included large numbers of minor cyprinids, *R. dandonicus*, *A. mellatinus* along with lesser amounts of predatory species, including *M.vittatus* demonstrating the high existing productivity of these systems. If intensified, such practices could harm natural recruitment. Alternatively there may be potential to use such catches for stocking enhancement in seasonal tanks. To extend the growing window this could involve visiting local system tanks that are likely to spill in advance of seasonal tanks (due to their receipt of diversion waters), though different assemblages and sizes of migrant fish are likely to be available from such tanks.

15.1 Fishermen's institutions and community based fisheries management

Only two fishermen's organisations were in existence at the time of survey, out of twenty-four tanks visited in the two cascade systems. Both were recently initiated with incentives offered by external organisations. Neither had proved particularly effective, whilst one had actually exacerbated latent NR conflicts in the target village of PDW. Case study 1 describes the recent attempts to form a co-operative in the Uriawewa system tank where unregulated artisanal and subsistence fisheries has previously been the norm.

Presented as a case study No 2 (Box 7) this gives an example of the conflicts that can arise when all the relevant stakeholders dependent on a resource are not considered prior to development interventions. Even if it is accepted that marginal groups who are the principal existing exploiters of the fishery must not be ignored, such groups are likely to lack visibility due to their poor representation in village level institutions. In addition they are likely to suffer from highest levels of social problems including alcoholism and illiteracy. For these reasons, and because of value-laden judgments, which label them as part of the problem (i.e. 'poachers') rather than part of the solution. Many traditional development approaches have neglected such groups completely, partly because their preferred way of life is so much at odds with conventional development strategies.

Assumptions that local community groups are the most appropriate socio-political units for managing or allocating resources may be ecologically and economically unsound in non-equilibrium resources systems such as seasonal tank fisheries, NERS, (McCain and Jones 1997 - see Box 6). The definition of community, and hence who is 'in' and who is 'out', is critical in this respect. Residential proximity is usually the key criteria with respect to access to a particular natural resource base, though this definition is obviously inadequate with respect to transhumance livelihoods in NERS. So far we have clearly defined the socio-economic, cultural and spatial boundaries of community within the concept of the PC. However there are good precedents to suggest that 'outsiders' who return to a specific area to exploit a non-equilibrium resource with regular periodicity will often take steps to manage the resource in a sustainable manner (McCain and Jones 1997). In this respect there exists a good case to extend the concept of community to incorporate the upper and lower watershed PCs where interdependence already exists with respect to the natural resource base. In terms of interventions the question then becomes how can we implement a strong institutional framework that includes both village and external agencies, capable of accommodating a flexible periodic tenure? Ensuring sufficient reciprocity between the different user groups to ensure sustainability will be critical. Possible avenues in this respect include the undertaking of maintenance activities (such as clearance of encroaching weeds, bund maintenance etc) by 'outside' fishermen, or strategic movements of locally available broodstock to overcome deficit years in the tanks they exploit.

Just as there is an increasing realisation that pastoral peoples are efficient users of marginal environments and need to be protected from encroachment by outside interests, it is becoming apparent that foragers need similar assistance. However, although, the recent prioritisation of poverty and marginalised peoples in development has refocused attention towards them, there has been no corresponding development in policy (Blench 1999)

Box 6. Transhumance livelihood strategies in Non Equilibrium Resource Systems (NERS).

In non-equilibrium resources systems, the spatial and temporal distribution of resource productivity varies unpredictably within recognised spatial limits (Behnke and Scoones 1992). In response to such unpredictability many social groups (including pasturalists, hunter gatherers and fisher-folk) have traditionally adopted transhumance strategies. Such strategies rely on diversity of economic strategies, reciprocity in resource access and flexible tenure institutions to ensure group members have access to key resources in sufficient quantities all year, from year to year. Essential to transhumance strategies are key fallback zones of sufficiently high productivity to ensure basic food security. The case of fish production in STCs within meso-watersheds is an example of an NERS around which transhumance livelihood strategies have traditionally revolved. Principal fallback strategies in this instance include small-scale dry-land agriculture, off-farm / agricultural labour and the traditional artisanal crafts of low caste groups such as potters, blacksmiths or wicker workers. At a larger scale, the seasonal migration of coastal fishermen to inland fisheries around major tanks represents a second example, though one that has proved unsustainable due to conflicts arising from increasing primacy of the resource to local user groups and socio-political factors (see Working Paper 2).

Box 7. Two case studies on the activities of fishermen's organisation in Pahala Diulwewa and Uriawewa tanks.

Case study 1: Uriawewa fishermen's co-operative: A modest size system tank at the base of the Uriawewa cascade, this tank is large enough to have a small commercial fishery associated with it involving 15-20 full and part-time fishermen. Although the tank had been stocked with tilapia and common carp provided by the government in the past, none of the fishermen had any recollection of any earlier co-operative activity. Shortly prior to our visit, a co-operative society had been established at the behest of the local fisheries inspection officer. However, no collective activities had been undertaken to date and all the fishermen interviewed were uncertain as to what was planned for the future, though the two respondents interviewed (both ordinary members) were hopeful of subsidies to buy new gears and further stocking initiatives. Low yields were currently reported as the tank had been almost completely drained for bund repairs during the previous year.

Case study 2: Pahala Diulwewa fishermen's organisation: Facilitated by a local NGO, a fisherman's co-operative consisting of ten members was established as a sub-group of the Pahala Diulwewa farmer's organisation during 1996. The same NGO provided the group with 5,000 free *Oreochromis niloticus* fingerlings, which were introduced into PDW tank early in the 96/97 *Maha* cultivation season. Previously, only *Oreochromis mossambicus* were present. It was agreed that 15% of the proceeds from the fishery, would go back to the farmer's organisation and the balance would be divided amongst the membership. The farmers invested labour in guarding the tank against poachers but subsequently harvested very few fish, suspecting heavy snakehead predation and the small size at stocking as the cause of the failure. In the following year the farmer's organisation failed to post prohibition notices after the previous years poor performance. However the tilapia had since become established and a relatively good yield was reported though relatively little of the benefit went to the now demoralized fisherman's organization.

Key informants including the president of the FO and the fishermen's society reported that 'antisocial elements' in the village had invited 'friends from outside' to participate in the fishery, undermining any subsequent attempts at management based on access restrictions. Thus little benefit accrued to the original membership of the organisation, which thereafter effectively ceased to function and instead a conflict situation briefly arose in the village. Further interviews with farmers outside the two organisations revealed that two of the principal 'antisocial elements' were amongst the few members of this upper caste village to have participated regularly in the fishery prior to the stocking initiative. Although invited to join the fishermen's organisation in the first instance they soon dropped out due to the restrictions placed on their former fishing activities. It further transpired that low participation levels prior to the intervention were in large part due to the village's high caste status (*Govigama* or farmer caste) and a perception that fishing is low status 'pity work'.

Further interviews revealed that some twenty low caste youth (of the *Kumbara* or Potter caste) from Ihala Diulwewa, the next villages up in the cascade were those responsible for the bulk of fishing that had earlier taken place in the tank. These were the same outsiders invited in by the 'anti-social elements' within the village during the second year. Although labelled as 'poachers' by members of the PDW farming organisation, these disenfranchised youth exploit the local fisheries for a combination or recreational and subsistence purposes. These groups are often the lowest status, amongst the poorest even in their own communities and often suffer from other social problems including widespread alcoholism. This makes them difficult to target using conventional approaches.

An interesting postscript to the story occurred two years later, when a bumper harvest of both *Oreochromis niloticus* and snakehead were recorded from Ihala Diulwewa tank. This shallow tank spills regularly into the lower Pahala Diulwewa tank providing a natural route for migration of the stocked tilapia, finally bringing direct benefit to the community, which currently relies on the fishery most.

15.2 Equity in sustainable watershed based fisheries management.

If watershed based development interventions are to be sustainable, equity and access benefits, as well as productivity, must be considered. Elsewhere this has proved to be a more difficult objective, particularly in resource-poor watersheds (Fernandez 1994). The landless or land poor are often further marginalised in many watershed development projects where the principle focus is towards those controlling land. If such groups are unsatisfied with benefits from the physical interventions of watershed development, they are more likely to continue unsustainable exploitation of the natural resource base with negative downstream impacts. The involvement and distribution of benefits to landless groups arising from improved management and increased biomass production within CPRs, including fish production, is recognised as an important means of improving equity and increasing the sustainability of watershed development programs (Fernandez 1994).

Townsley (1998) comments that traditional forms of indigenous regulation of communal aquatic resources have in the past ensured their sustainability. However the rules affecting access to the same resources are often ill defined, subject to various interpretations by different stakeholder groups and it is the poorest groups who often lose out when pressure on these resources increases. Furthermore traditional management systems have been driven by a variety of considerations including the status of individuals and communities, reciprocal exchange and other cultural/ceremonial values. Resource conservation has not always figured explicitly amongst these considerations and the concepts of equity and user participation in decision-making, pre-requisites of sustainable resource management, may represent new or unfamiliar priorities. It is therefore not possible to make generalisations regarding the potential benefits of traditional mechanisms to emerging resource needs and assessment is required on a case-by-case basis.

The traditional systems of a dry season fishing ban followed by collective harvesting in STCs continue to be widely practiced despite demographic changes and a shift in social values which created the taboos formally used to enforce bans. These patterns appear to meet today's needs, as water for dry-season bathing is now a priority and little effort is required to harvest fish at the end of the season when water levels are low. Although organisation of these events through bans, collective fishing and harvest distribution mechanisms, has become increasingly informal, a good degree of equity is preserved in their contemporary practice (Working Paper SL1.2). This offers good scope for their inclusion in enhanced fisheries systems, which aim to sustain or enhance production.

Such interventions must aim to stimulate enforcement of access and fishing rights and be compatible with clearly defined and easily understood water management practices. Clearly strong community based institutions are required. These institutions should encourage a transparent and equitable distribution of benefits inclusive of those currently having greatest dependence on the resource for subsistence purposes (see Box 7) with net direct or indirect benefits also going to other water-users within the community to avoid conflict. In the local context, fisheries enhancements in upper watershed areas may also be compatible with the preservation of these areas as buffer zones between uncolonised forest areas and outlying areas of human settlement.

Direct benefits could include a share in the harvest of fish based on individual participation in management of the fishery, possibly with some secondary distribution according to local norms. Income may be generated through sales of any fish harvested or perhaps through the sale of fishing rights to external fishing rights to external participants. Indirect benefits may also then accrue through improved availability and lower cost availability of fresh fish in the village. Enhanced employment opportunities in processing or value addition or through a share of any profits contributed to village development, both physical and institutional could also be expected. In this respect funds donated to the Farmer Organisation (FO) may be used to improve management and maintenance of the tank itself, also encouraging the co-operation of farmers who use water primarily for irrigation. Donation of funds to Death Donation Societies may bring benefits to a wider membership than is normally encompassed by FOs. Many villages also have village development societies who undertake small communal development tasks, which could also be supported.

16 Constraints to aquaculture; perceptions of farmers.

Farmers in DWD and PDW currently participating in fishery related activities or expressing interest in aquaculture uptake, were asked to rank and score what they perceived to be the most important constraints to the practice of aquaculture in their village tanks. Such interest was generally confined to small numbers of youth and younger farmers. Negligible interest was elicited amongst village women or upper wealth groups. Three criteria were identified, predation, poaching and water availability. Surprisingly lack of knowledge was not identified as a constraint. In this respect, farmers in focus groups demonstrated poor understanding of the prerequisites for culture-based production, but good appreciation of the range of wild species available, their ecology (see Box 7) and based on this knowledge, they demonstrated an in-depth knowledge of capture techniques suited to different environmental conditions and seasons of the year (see section 15). Results of ranking exercises were analysed using Friedman's test, the results of which are shown in appendix 3. Significant concurrence was found in both villages ($P > 0.05$), with farmers ranking water availability and poaching above predation. In DDW lack of water was clearly ranked highest, reflecting the greater seasonality of this village tank. Farmers weren't very sure about how these constraints could be overcome, but in Pahala Diulwewa where stocking had already taken place, (see Box 5) farmers suggested that fingerlings should be nursed in cages to a suitable size at which they are better able to resist predation.

16.1 Stock containment

Loss of stocked fingerlings during spill events is cited as a major constraint to earlier enhancement initiatives in seasonal tanks. The magnitude of spill events recorded in the present study suggests that it will rarely be possible to use barriers placed over spillways to contain stock. Furthermore greater losses are likely to occur through preventing upstream migration of juveniles than more the more passive downstream losses over spillways, depending on design. Other options are the containment of fingerlings in cages or pens until floodwaters reside or post-spill stocking. High initial input costs, labour requirements, and uncertainties over access to the released stocks mean such options are likely to be non-viable. Alternative options based on stocking of tanks at strategic migration nodes i.e. taking advantage of spill events are likely to find more application (section 11).

16.2 Predation pressure

Sri Lanka has the highest level of biological diversity in SE Asia. This diversity brings with it a tremendous range and number of predators including birds, reptiles, amphibians, mammals and fish. In the local Buddhist culture few of the non-fish predators are culled or consumed. Consequently in the perennial fishery it is estimated that such predators remove an equal amount of fish as the human fishery (De Silva 1988). Mee (1993) reports that protected grow out ponds can achieve harvest rates better than 90% of stocked quantities, whereas unchecked predators can reduce harvest rates to as low as 20%. Where steps can be taken to reduce predation pressure, dramatic increases in yield can be expected, particularly in semi-intensive culture systems.

Greatest potential for predation occurs when fish become concentrated in the receding waters of shallow seasonal tanks during the dry season, a period when alternative water and food supplies for a wide range of wild fauna are increasingly scarce. Although it may be possible to exclude water-based predators such as snakehead at this time, it is much more difficult to exclude terrestrial and airborne predators. Farmers felt this represented a significant constraint to early season stocking options, as water levels in such tanks will often rise and fall repeatedly with the progressive onset of rains, before reaching maximal waterspread. However the same rains rapidly 'green' the land, bringing with them a wide range of alternative food/drink resource that are likely to deplete predation pressure on the filling tanks. Further research is required to understand the relationship between the timing of tank filling and the relationship between tank depth and predation dynamics.

Novel, low-input and environmentally friendly methods should be investigated in participation with farmers who have demonstrated good knowledge of the local ecology (see Box 8). These may include provision of refuge areas, including excavated areas and brush parks. With the suitable design and placement, brush parks, may provide shelter for juvenile fishes from animal predators and human poachers alike and act as periphyton substrates. Alternatively locally sourced broodstock, which are more predator-resistant, could be stocked for *in-situ* fingerling production although this option offers a smaller growth window than the use of advanced fingerlings (see Working papers SL1.1 and SL1.2).

Box 8. Indigenous knowledge of predatory interaction in tilapia / snakehead capture fisheries.

Although the benefits of snakehead predation on management of tilapia stunting in polyculture are well recognised, little evidence exists regarding the impacts of predatory behaviour by tilapia on other species. Two species of snakehead are commonly recognised: *Channa striata* (*loola*) and *Channa punctata* (*madda kannaya*). Farmers referred to the more diminutive second species as the 'small master of the tank' as it is commonly found in significant quantity only when the larger *C. punctata* is absent. Farmers provided detailed descriptions of the early life stages of snakehead, which were triangulated by repeated interview and visits to breeding sites with some of the same farmers. In contrast to the mainly riverine indigenous freshwater fish fauna, snakehead were observed breeding *in-situ* in shallow littoral waters of seasonal tanks. Peak spawning effort takes place during periods of increasing and maximal water spread, between October to January. Having spawned 500 to 2,000 orange eggs (farmer estimates), the adult fish remain close to their nests to guard the eggs until they have hatched. Subsequently, the fry shoal together in shallow water for up to four weeks until they take on their darker adult pigmentation replacing the orange colour of the early life stages. At this point having grown to 2-3cm in length, they disperse to lead solitary lives in deeper waters.

The predatory skills of the snakehead were well recognised, one farmer stating that 'they rarely miss their mark'. However many farmers also reported that adult tilapia successfully take snakehead eggs and juveniles particularly when their numbers were too great for the parent to guard the nest successfully. The fact that prey/predator relationships exist in both directions suggests that the dynamic equilibrium that must exist between the production levels of the two species must be more complex than originally thought. Anecdotal evidence suggests that under suitable conditions, elevated production of both species is possible where they occur together. Future research will aim at gaining better insight into the existing productivity of these systems – most readily through the assessment of landings during communal harvesting events.

Farmer observations also have relevance to seed availability for local sourcing options. During this juvenile shoaling phase, fry are most easily observed during the first daylight hours when they move into the shallowest littoral waters. These early morning events are known locally as *'petav polas'* (literally baby fish markets). Traditionally, children familiar with their occurrence catch the juveniles with ease at these times. Great potential therefore exists to harvest such juveniles for strategic stocking options, particularly in more seasonal tanks. Tilapia broodstock could be stocked early on in these tanks for *in-situ* fingerling production and subsequently snakehead fry spawned later in the season to enhance the prey/predatory synergy.

16.3 Disease

Farmers who consumed fish caught from Uriawewa said they disliked eating the catfish *Mystus vittatus* and another unidentified species, because of the high incidence of external worm infection in these species, probably *Lernea* Sp. In Danduwellawe farmers described an increasing prevalence of a disease infecting snakehead in Ankendawewa and Mahawewa. The ulcerative pathology described and observed was strongly suggestive EUS (epizootic Ulcerative Syndrome) caused by the *Aphanomyces* fungus to be the likely cause. Unlike most fish diseases EUS has had greater impacts on extensive lower input systems and wild fisheries than on controlled intensive culture meaning that poorer rural producers, traders and consumers alike have suffered the worst impacts (Bhaumik et al 1991). The first recorded outbreak occurred in Western Sri Lanka in 1987 affecting both freshwater and estuarine fish (Costa and Wijeyaratne, 1989). It is suspected that the disease was imported from SE Asia in a contaminated batch of ornamental angelfish (Bala suriya 1994). Whilst tilapias are largely resistant to infection, snakeheads are amongst the most susceptible species. Recently infections of climbing perch (*Anabas testudineus*) and giant gouramy (*Osphronemus gouramy*) were confirmed in Thailand (Lilley et al 2000). These species are of subsidiary importance in local seasonal tank catches. Susceptibility amongst carp species is variable, ranging from highly susceptible *Puntius* sp. to largely refractory common carp and rohu and moderately susceptible mrigal (Lilley 1998).

Although the fungus is most virulent during cooler periods (<21oC), the most severe local outbreaks were reported in seasonal and semi-seasonal tanks during periods of low water-spread. This is probably due to a range of increased environmental stresses i.e. increased stocking densities, acid runoff in poorly managed watersheds, secondary infection by other organisms especially ecto-parasites etc. Predisposing skin lesions are a necessary pre-cursor to fungal invasion. These factors are most likely during the period when snakehead are most readily harvested from these tanks. This has negative impacts on consumer perceptions, which reduces the demand for snakehead from seasonal tanks in commercial vendor networks (Working Paper SL1.4).

Migration of infected fish and discharge of infected water can be expected to spread disease outbreaks up and down cascade systems. In this respect, farmers reported the recent outbreak of infection in Mahawewa, following an outbreak in the lower Ankendawewa tank and a subsequent spill event linking the two. Fishermen estimated some 30-40% of all fish caught during these episodes showed signs of infection. Mass mortalities associated with an outbreak in Ankendawewa during 1995/96 were reported to have resulted in water pollution and temporary loss of amenity for domestic, livestock usage and even inhibited the consumption of refractory fish species in the tank. Interestingly there were fewer reports of serious out-breaks in the most highly seasonal tanks. This is possibly due to the fact that *A. invadans* propagules are not resistant to desiccation and will be eliminated where the bottom mud dries out completely during the dry season. Liming of tanks or removal of residual mud at this point could also be used as a means of eliminating the disease (Khan et al 1999). Lime applications will also improve the buffering capacity of water, helping to reduce infection through maintenance of the integrity of fish skin. Staggered harvesting options, which prevent excess build up of fish biomass concentrations as well as good catchment maintenance are also important management tools, which can reduce predisposition to infection. Productive ‘green’ waters, with high densities of phytoplankton, have also been shown to support lower concentration of infective fungal oomycetes than clear water, representing another possible management tool (Lilley 1992, Khan et al 1999).

Although the recorded severity of EUS outbreaks has decreased over recent years, there is still widespread occurrence, particularly throughout SE and S Asia. Perhaps because the fungus does not affect the main commercial species tilapia, no recent record of the disease in freshwater environments could be found in the literature relating to Sri Lanka. The last reported occurrence found in the literature was in Batticaloa lagoon on the East Coast in 1996 (Lilley et al 1998) and it would appear that in Sri Lanka the incidence of the disease is declining naturally as natural resistance is built up in the remaining population pool.

16.4 Aquatic macrophyte infestation in seasonal tanks

Salvinia molesta, water hyacinth (*Eichornia crassipes*), lotus or *nelum* (*Nelumbo nucifera*) and water lily or *olu* (*Nymphaea Sp*.) are surface encroaching aquatic weeds, which are causing major problems for both irrigated agriculture and fisheries and observed in the current study. A fifth species azolla (*Azolla filiculoides)* that is host to a symbiotic nitrogen fixing blue-green alga or cyanobacterium (*Anabaena azollae*) also of the salvinia family (*salviniacieae*) was encountered only in one tank. Its presence is noteworthy as elsewhere in SE Asia this species has been successfully incorporated into integrated aquaculture systems because of its high nitrogen content and quality as a direct feed for ducks and fish.

The first two species are floating macrophytes that propagate principally by vegetative division. Both are exotic introductions. *Salvinia* has been cause for particular concern, having spread widely since its introduction in the 1940's. Between 25-50% of Sri Lanka's 30,000 tanks and an estimated 30,000-50,000 ha of paddy-lands are infested by *Salvinia* (IIMI 1998). Under favourable conditions in stagnant water it can double in area every two days resulting in blanket coverage. Water lilies require a substrate within which to root but can still become established in up to 2m of water (pers. obs.). All these weeds result in blanket like surface encroachment though *Salvinia* creates by far the densest cover impenetrable to light in extreme cases, followed by *Azolla*, water hyacinth and finally lotus and water lilies. Negative impacts on fisheries from infestation include: removal of nutrients and competition for sunlight reducing primary productivity, potential oxygen depletion and release of noxious gasses (nitrogen sulphide and methane) as layers decompose on the tank bed. Only air breathing fish such as catfish and snakehead can thrive in the most heavily contaminated systems (Edwards 1980). Fishermen have reported they can no longer use their boats in heavily contaminated waters where *Salvinia* can grow up to 3' thick (The Sunday Times 1998). These weeds also impacts on agriculture through accelerated tank siltation, whilst *Salvinia* routinely blocks sluice pipes and drainage systems and can even infest the farm subsystem.

Although all these weeds can be used as a useful compost (particularly water hyacinth with it's high potash content) or mulch, this is extremely labour intensive due to their high water content and effort that would involved in cutting, carrying and drying these weeds. Nowhere was such use seen or reported in practice, even on a small scale. Edwards (1980) suggests that a more practicable use of aquatic macrophytes may be to use them as organic fertilisers in fishponds, if the cut weeds are stacked and allowed to rot before application (avoiding recontamination by viable plants). Two to three applications of around 1,680 kg/ha/application administered at 3 monthly intervals are sufficient to lead to the production of a good plankton bloom.

However of the five surface encroachers identified, only lotus and water lilies were observed being put to a productive purpose, the rhizomes and seeds are edible and occasionally harvested for self-consumption or sale. In one case study from the Punjab, rhizome productivity was estimated to be around 3,787 to 4,734kg/ha Edwards (1980). This represents an attractive potential return with farm gate prices in the current study at Rs11/kg as the crop requires negligible cultivation effort. Lotus flowers are harvested and sold for religious purposes, this being a sacred plant in Hindu and Buddhist religion. A range of other small leafy emergent vascular plants growing in littoral areas are also widely collected for use in sambol and curry dishes.

Generally the negative impacts of the floating variety of weeds greatly outweigh any potential benefits, though farmers were unaware of these negative impacts. A frequent comment was that 'surface encroachment conserved water through protection from evaporation', when in reality losses are more likely to be accelerated through evapotranspiration in addition to reductions in storage capacity. The evaporative losses associated with salvinia infestation can be anticipated to be particularly high owing to the extremely high surface area presented by their convoluted and hirsute leaf structure.

Initial attempts to control the *Salvinia* problem in the 1950's relying on the use of paraquat were soon abandoned due to the high cost of applications and environmental concerns. The method currently favoured is early physical mechanical removal, though a biological control method using the weevil *Crytobagous Salvinia*, which feeds on the weed, has given some positive results. Released in 96 tanks from 1986 to 1989. the weevil gave effective control in 16 cases and near success was reported in 23 cases. However for the weevil to survive tank levels must not drop below 2', reducing its efficacy in shallow or seasonal tanks without repeated introductions.

Table 12 shows estimates of encroachment for surface weeds in addition to emergent aquatic grasses. Tanks are presented in their cascade hierarchy from upper to lower watershed (see also Figs 5 and 6). These observations were made during the month of December and therefore represent only one point in a dynamic equilibrium governed by the seasonality of each tank. Generally, minimal encroachment levels can be expected when tanks are at maximum water-spread, particularly when they fill rapidly, whilst maximal levels can be expected during periods close to lowest water-spread as existing cover becomes more concentrated. This has negative impacts on the harvestability of fish, particularly in more seasonal tanks. Although rains during the current season were late and most tanks only half full, much of what had been stored fell during the previous month presenting a modest window for re-colonisation. Results presented therefore represent an interim status between the extremes described above. Current government recommendations prescribe the stocking of severely encroached tanks, a policy, which is more likely to exclude semi-seasonal and seasonal tanks in favour of interventions in larger perennial tanks.

The results show that *salvinia* and hyacinth infestation is yet to emerge as a serious problem in the systems studied affecting only two and one tanks in DDW and PDW cascades respectively, out of a total of 24 tanks investigated. However more extensive infestation was frequently observed in neighbouring cascade systems. Downstream routes of transmission include spill events[52] and drainage waters. Water buffalo are reported to be the principal means of upstream and trans-basin transmission, (IIMI 1998). Many key informants in the current study reported fishermen using contaminated gears as the principle agents of transmission. Having become established at the base of two cascades the likelihood of upstream migration of these exotics is great in absence of any coordinated efforts to block these transmission routes. Once upper watershed tanks are infected it is only a matter of time before spill events result in contamination of the whole system.

[52] During spate large amounts of salvinia were observed cascading downstream with spill water and contaminating lower tanks.

Table 12. Estimated percentage of tank surface area encroached by aquatic macrophytes, during December 1998 within 3 cascade systems

Tank Ref Code.	Tank Name	Salvinia %	Hyacinth %	Lotus & water lilly %	Emergent grasses %	Comments
Danduwellawe cascade						
DAN3	Aluthwewa	0	0	0	90	Silted / v. shallow
DAN2	Bundapuwewa	0	0	30	10	
DAN1	Mahawewa	0	0	5	10	
ANK4	Ankendawewa	0	0	50	10	
ANK3	Kottagasyawewa	0	0	0	80	Silted /v. shallow
ANK2	Kumbukwewa	0	0	50	25	
ANK1	Rathmalewewa	0	0	15	30	Silted / v. shallow
MGW1	Mahagalkadawala	0	15	70	10	
Pahala Diulwewa cascade						
IDW3	Madatuwa	0	0	0	10	
IDW2	Ihala Diulwewa	0	0	0	30	Silted / shallow
IDW1	Neluwawewa	0	0	0	5	
PAR1	Pinwewa	0	0	0	20	
PDW3	Siyambalagaswewa	NA	NA	NA	NA	
PDW2	Ihala Sembugama	0	0	60	20	
PDW1	Pahala Diulwewa	0	0	70	20	
SEM2	Koromdawewa	NA	NA	NA	NA	
SEM1	Pahala Sembugama	30	0	70	20	
PAL1	Paliagama	5-10	0	30	5	
Uria Wewa cascade						
PDW6	Ulpathwewa	0	0	0	5	
PDW5	Keeriyagahawewa	0	0	5	10	
PDW4	Palugaswewa	0	0	0	0	
URI 3	Morankulamwewa	0	0	80	5	Silted / shallow
URI 2	Wayrankulamwewa	0	0	0	5	
URI 1	Uriawewa	0	0	0	0	

The distribution of established indigenous water lilies and emergent aquatic grasses reveal some interesting patterns. The highest levels of water lily encroachment occurred in the mid-level tanks, where the shallow, sheltered and semi-seasonal nature of these tanks represents an ideal environment for their growth. In the deeper perennial base tanks their growth is restricted to shallower literal areas, whilst growth of these and all other truly aquatic weeds in the radial tanks of upper and mid watersheds are checked by their highly seasonal nature. However, even here, rooted water lilies and emergent grasses are most likely to persist where muddy areas remain to protect their tubers. Under such conditions these water-bodies are rapidly recolonised as tanks refill with the advent of new rains.

The highest levels of coverage by emergent grasses were found in uniformly shallow tanks, including smaller radial tanks and neglected mid-watershed tanks in advanced states of siltation (these species being more resistant to desiccation than the macrophytes identified above). One such tank, Ihala Diulwewa (a semi-seasonal 'temple tank of 12ac max water spread) was reported to have an unusually productive tilapia and snakehead fishery. Favourable growing conditions found within this tank are as follows. With very limited irrigation demands (see section 11) water levels can be expected to retreat more steadily than in most tanks with higher irrigation demands. This results in an extensive area of uniformly shallow and stable depth occupied by emergent grasses, leaving a relatively small deeper-area of free-water close to the bund. Furthermore the tank is entirely free of floating macrophytes, allowing good light penetration, whilst the grasses act directly as periphyton substrates in addition to providing breeding sites and shelter for juveniles.

Based on these preliminary findings, it is recommended that improved methods of integrated management of nuisance weeds including means of prevention and remediation should be researched in participation with villagers. Regular manual clearance in affected tanks would seem to be the most practicable means of management in affected tanks. There may be potential for fishing groups to undertake this activity as one means of returning some of the benefits of their assured access to the fishery back to the wider community. Care should also be taken to ensure areas excavated to provide fish refuges in seasonal tanks over the dry-season do not also harbour encroaching macrophytes, which would normally be eliminated. The positive aspects of many aquatic macrophytes should also be acknowledged i.e. retention of some areas of emergent grasses, as feeding and nursing areas will be advantageous.

17 Summary: aquaculture potential in small-scale water bodies

Following is a summary of the technical constraints and opportunities for aquaculture in different sub-sections of irrigation systems and other small water bodies encountered in project villages:

Fish in Rice: Existing rice cultivation methods and water availability patterns are not suitable for fish in rice production. Although adverse cultivation practices (broadcasting or transplanting, pesticides or Integrated Pest Management) could potentially be modified, water availability is the greatest constraint. This is most critical in the upper catchments where some of the poorest communities encountered have the water resources to practice only supplementary irrigation. Better potential may exist under larger tanks lower in the watershed where the frequency of water issue is greater. Additionally this practice would yield fingerlings in February or March, unsuitable for the stocking of seasonal tanks.

Agro-wells: Technically, good potential appears to have been demonstrated for production of advanced fingerling in strategically located agro-wells. These are widely distributed private resources, most are perennial and many are not used for consumption purposes, particularly where salinity is high (see Appendices 4 & 5). Although no sustainable adoption has so far been reported. The investment in labour and other inputs to achieve the level of intensification required for consistent success using this system may be incompatible with the existing priorities and needs of the community (see Working Paper 5). The lack of existing markets for food fish fingerlings also represents a significant constraint to adoption of semi-intensive production systems (see Working Paper 6).

Borrow pits: Pits commonly associated with tank construction and maintenance are common property resources giving good access to landless members of the community. Though small in size they offer potential for advanced fingerling production or provision of refuges for enhancement of natural fisheries, although there may a conflict with usage for livestock watering during the dry season (see Appendix 4).

Flooded quarries with good water holding capacity offer potential for grow out or fingerling production depending on their size and accessibility. A trend amongst farmers to invest in permanent house construction has resulted in the creation of substantial numbers of these structures. This had also led to a proliferation of borrow pits for brick production, however retention in these structures is extremely poor, offering little potential for aquaculture.

Seasonal Tanks: Seasonality in these systems requires more careful definition, with respect to aquaculture potential. Farmers typically defined seasonality with respect to water availability for irrigation and only the smallest and most neglected tanks were found to dry completely on a regular basis. A whole range of opportunities and constraints for aquaculture are presented by the variety of habitat conditions in these tanks. As we have seen, many of these opportunities and constraints, both socio-economic and technical are reversed at different levels of the watershed, therefore good potential for synergies exist if different components of the production cycle (i.e. fingerling production, nursing and grow-out) can be assigned to different classes of tank. Alternatively watershed planning which enhances migration pathways and potential for natural recruitment represents the least extensive and perhaps sustainable option in a context where farmers put a low value on fish stocks and are likely to seek to minimise labour inputs rather than maximise output. This option would also to be more feasible where social barriers hinder the active co-operation of neighbouring communities. Further details on enhanced fisheries options are presented in Working Paper SL1.2.

18 General conclusions.

The enduring presence of strong kinship linkages defining discrete communities is clearly central to the understanding of current patterns of natural resource management at the watershed level. Such linkages take on greater relevance in the context of weak institutional and collective decision making capacity at village level. The Purana Complex with its cluster of associated tanks should be the smallest logical unit for development intervention within the watershed framework rather than an individual tank/community focus that has been the norm to date.

Wealth disparities are likely to exist both within and between PCs, however due primarily to decreasing water availability, the poorest PCs are still most likely to be located in upper watershed areas. In lower watershed areas constraints to aquaculture include a lower dependence on local tank-based fisheries in favour of commercially available produce. Moreover decision making about water use more complex, due to the larger size of communities and the more intensive cultivation they undertake. As cultivation opportunities in upper watershed areas are limited, these communities have the greatest relative dependency on exploitation of natural resources / CPRs including tank-based fisheries. However where limited access to perennial water resources exists with in their own PCs, such groups are likely to exploit neighbouring tanks in a wide radius around their own PCs. Although such 'poaching' is generally well tolerated at low levels, potential for increased conflict exists where hitherto free access is impeded by carelessly designed development interventions, which target unrepresentative FOs and unsuitable communities. The enhancement or maintenance of existing livelihood strategies based around tank fisheries may have potential to reduce the unsustainable exploitation of other natural resources such as logging and quarrying in catchment areas, if equitable benefits are shared amongst the resource poor. One of the greatest challenges for future research lies in overcoming the mismatch between need and resource access outlined above.

In addition to the well-recognised technical constraint of seasonal water availability, aquatic production is also limited by resource flows including: nutrients, migratory fish stocks, disease and encroaching macrophytes which move in both upstream and downstream directions of which greater understanding is also required.

These findings indicate upper watershed PCs should become the main target groups for fisheries interventions but that a continued watershed focus is also essential for integrated and sustainable management of the natural resource base including fisheries. A participatory research agenda for farmer managed trials based on the findings presented in this and the other working papers is included in Working Paper SL1.1.

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Appendix 1: Hydro-geological regions of Sri Lanka.

A1.1 Hydro-geological regions of Sri Lanka.

The North Western and Northern Coastal Belt: This belt of sedimentary Miocene formations covers 10% of the island extending from Puttalam to the Northern Jaffna Peninsular. Miocene deposits overlaid by quaternary alluvial deposits form highly productive aquifers. Wells reaching these aquifers in well-defined basins have an average depth of 30-50m. Yields range from 5-25 l/s with drawdown of 5-15m. These waters show moderate conductivity with salinity increasing with depth.

The Eastern, South Eastern and Western Coastal Belts. Here discontinuous but productive aquifers in lagoon sands and alluvial deposits are dominant. Average depth is 3-5m and yield varies from 4-6 l/s. Water quality is good to brackish.

Crystalline basement complex: This hard rock region covers nearly 80% of Sri Lanka and nearly two thirds of this area falls within the dry zone. These hard rocks show no primary porosity and groundwater is only found in the fractured and weathered zone. The weathered zone extends from 2-10m in the dry zone. The weathered rock aquifer is highly exploitable and most people meet their domestic demand form dug wells constructed in this zone. Yields are generally low, often less than 4 l/s. Water levels are generally in the range of 3-20m (including fracture zones) and show a seasonal variation of 4-5m.

A1.2: Guidelines for agro-well location in STCs.

IIMI (1994) produced the following guidelines for assessing ground-water availability prior to planning the distribution of agro-well construction under STCs. The critical density of ground wells should also be considered during tank rehabilitation planning.

- Estimates of water consumption associated with different types of land use within the catchment area are assessed from a 1" (or 1:50,000 where available) survey map.
- Average recharge is assumed to be 110 mm/yr of which 50% is available for extraction, 160 mm/yr within the tank water spread and 150 mm/yr for rice irrigated land.
- The sum of these components gives a total estimate of ground water availability.

Appendix 2: The current status of watershed management in Sri Lanka

Watershed development involves the use of many interventions that are required for the introduction of sustainable aquaculture systems. This includes; rainfall harvesting, the prevention of soil erosion, and the sustainable enhancement of the production of fodder food, associated manure and fertilisers. The catchment scale of land management (rather than the individual farm) is now widely established in other regional states with arid and semi-arid environments. For example the Indian Government is spending about US$300 million per year on these projects (Barr 1998). This is logical when one considers the upstream and downstream biophysical and socio-economic impacts of different land and water use systems within this wider ecosystem. Different development models are applied depending on the scale of the watershed. In relatively large watersheds (>10,000), contiguous meso-water sheds potentially containing many villages are developed simultaneously. Or meso-watersheds (<500ha) may be developed on an individual basis (Samuha. pers. comm.).

Despite proud 2,000 year history of watershed management today little consideration of the benefits of watershed level approaches exists in Sri Lanka. Land degradation affecting all agro-ecological regions is taking place at an alarming rate. Despite the efforts of several government and non-government organisations to promote soil conservation, hardly any progress has been made during the last few decades.
Over-exploitation of land due to over population has resulted in total forest cover declining from 74% of total land area at the turn of the century to 22% (1.5 million ha) in 1995. The resulting soil erosion is the main cause of land degradation. De Alwis (1981) estimated an average soil loss of 40 mt/ha/yr over the last century. Cover continues to decline at 3.5% per year. Clearance of forest from reservoir catchment areas has dramatically increased tank siltation rates. Other unfavorable ecological consequences include decreased levels of natural productivity when reservoirs are deprived of the organic inputs normally flowing from forested catchment. This impacts on both fisheries and land productivity. Soil erosion is directly associated with the type of land use. In the dry zone, rainfed chenna (shifting slash and burn) cultivation remains the most destructive practice (see Box A2.1), with degradation accelerated further as the potential for fallow periods reduce. Of the total land area in Sri Lanka (6.5million ha) it is estimated that 1 million are still under shifting slash and burn cultivation of which 0.2 ha are annually cultivated (Gamage 1995). In addition to illegal encroachment, landless farmers are often resettled in such degradation prone lands further exacerbating the problem.

Box A2.1. Soil losses from cultivated lands in Reddish Brown Earths – Alfisols of the low country Dry Zone.

Crop	Tons/ha/yr
Sorghum/Pigeon Pea	21.3
As above with mulch	3.9
Cotton	22.2
Cotton with mulch	2
Newly cleared chenna, 45% slope	100

Source: Gamage 1995.

Deficiencies in government policy, legislation, institutional commitment and responsibility, lack of suitable extension capacity, unavailability of incentives for poor farmers, short term projects (often with no concern for sustainability, poor co-ordination amongst implementing agencies, poor participation at grass roots level and village organisations, have been cited as reasons for the worsening situation. The National Environment Action Plan 1992-1196 (NEAP) funded by the world bank and USAID was a 5 year plan based on national priorities and the assessment of resource availability, including preventative and corrective measures in water and land resources. Benefits have been confined to a few geographical areas and. A second plan (1997-2000) is now underway. Many of the IRDP programs promote soil conservation levels, but non-of these programs are exploiting the benefits of operating at the wider watershed level.

Where interventions are made combinations of biological and mechanical methods are applied. Biological measures include; avenue cropping (agro-forestry and alley cropping), multi-storey cropping, and mulching and contour vetiver grass hedgerows. Mechanical methods include; contour platforms, level bench terraces, stone terracing, contour drains and bunds. These can all be classified as in situ methods conservation measures, designed to encourage interception of rain water where it falls or reduce the velocity of erosive flows. Murray and Felsing (1998) reported a wide variety of 'ex-situ' soil and water harvesting devices employed in a watershed development program of Karnataka state. These include check dams, and farm ponds, small water bodies (<0.1ha) which were identified as having unexploited potential for aquaculture.

Appendix 3: Rehabilitation strategies for small-scale farmer managed irrigation systems in Sri Lanka.

A3.1. Bilateral government rehabilitation programs

A3.1.1 The village irrigation project (VIRP) – Commenced in 1980 this was the largest rehabilitation scheme in terms of area covered and cost. It covered 14 districts, almost the entire dry zone, targeting 1,200 minor schemes benefiting up to 25,000 families (World Bank 1981). The program was characterised by a top down bureaucratic approach with lack of co-operation between the two major implementing agencies; the Irrigation Department and the Department of Agrarian Services (DAS), who were assigned to deal with the physical and human (operations) resources respectively in a compartmentalized manner.

Selection of tanks was imposed from outside the community discouraged farmer participation. Selection of tanks was often contrived to benefit elite's, with such misappropriation facilitated by the poor standard of data held in the paddy lands register of Agrarian Service Centres. Construction works were tendered to the lowest bidder rather than the farmers themselves. Consequently farmers had little or no participation at any stage of the process from, design, planning and construction, such decisions being entirely appropriated by the irrigation department. Similarly the DAS effectively monopolised operations through it's 'Water management program' aimed at extending the command area through improved management efficiency. This had three components: An agricultural planning team (APT), which implemented the above program, a cultivation officer with legal rights to resolve conflicts and act against farmers violating government rules and a 'tank committee'. This committee consisted of village level government officials along with a few farmers' representatives and would meet to approve the plans formulated by the APT. The farmer representative who supposed to replace the old Irrigation headman (*Velvidane*) was effectively disenfranchised by this arrangement.

In addition to these short-comings, ARTI (1986) questioned whether such a committee, modelled on the 'one tank one village concept' was relevant in a modern setting of state penetration and demographic change. For instance because of land fragmentation (90% of holdings less than 1acre), the primacy of paddy cultivation in farmer's livelihood strategies is much reduced. The high investment and general lack of participation in this program generally resulted in farmers feeling that the state owned and managed the scheme, inducing further reluctance to form committees and a general culture of dependency. More importantly, this approach entirely excluded water users including fishermen who did not hold any land under the tank.

By 1989 the Irrigation department had completed nearly 90% of it's target number of tanks, which were then handed over to the DAS. The water management program under the DAS (which only started in 1983) had completed slightly more than it's target of 500 tank. Due to high levels of investment the program has brought significant physical improvements and increased water availability. However due to the lack of farmer participation from the very beginning of the development process, it's use as a model for farmer mobilisation and efficient water management and sustainable system management is extremely limited. High investment in physical repairs with minimal involvement has undermined their sense of ownership and subsequent participation in sound operational management practices.

A3.1.2 The Integrated Rural development program (IRDP): IRDP's were a culmination of attempts to decentralise the development process in the early 1970's. They were designed to target resources at those areas that did not benefit from development efforts under the Mahaweli Project. Unlike the VIRP irrigation was only one of many different sectoral sub-components under the IRDP. The Irrigation subcomponent included major and minor systems developments, though the latter has been given priority. Beginning in Kurunegala, Hambantota and Matara in 1979 they subsequently extended to 14 districts of the dry zone. The project permitted maximum freedom for planning and implementation at the district level. Although the VIRP and the IRDP share the same implementing agencies (the Irrigation Department and the DAS) the latter program benefited from greater horizontal and vertical coordination with other agencies. Establishment of administrative tiers below the district level, helped the IRDP to establish stronger farmers organisations than the VIRP, by penetrating to grass roots level.

Two IRDP models evolved as a consequence of this planning flexibility. The two most important bilateral programs, funded by the World Band and the Norwegian Agency for Development cooperation (NORAD) illustrate these approaches.

A3.1.2.1 The World Bank strategy initiated in Kurunegala District was similar to the VIRP 'blue print approach' focusing mainly on the irrigation component. This extended to five other districts including Puttalam., Focus was on rehabilitation of existing schemes thus completely abandoned schemes were not refurbished. On completion in 1988 453 (of 500 planned) village schemes were completed at a cost of US $3.7 million. The irrigation department had sole responsibility for selection of these schemes. Although the quality of physical works increased as the program progressed (with command areas increased by at least 10%), improvements in management were compromised by lack of early involvement of farmers as in the VIRP. The program replicated in Puttalam recorded some improvements in water management based on the experience of the Kurunegala project.

A3.1.2.2 The NORAD funded program in Hambantota (the HIDRP). Here a rolling planning strategy was evolved, which incorporated a systems approach within an integrated development package. This was quite different from the WB blue print approach. Recurrent planning occurred whereby information from on-going activities was continuously fed into a revolving planning procedure and planning, implementation and monitoring practices were strengthened at the district level. District level proposals were subject to regular review by NORAD and the ministry of plan implementation. The participation of both sexes was also stressed. Over one third of investment in the program was on irrigation work. Greatest investment was made on diversion schemes (20 anicuts) and rehabilitation programs under perennial tanks. This included complete reclamation and refurbishment of 18 tanks and the creation of three associated settlements. The village tank component was relatively small in this instance. Forty tanks in the West were targeted for repair (bund strengthening, sluice, spillway and channel system improvements). All project activities were identified and organised with active participation of farmers. Supplementary agricultural programs (water management, agricultural credit and crop cultivation) were incorporated into all these irrigation sub-projects. The NGO Sarvodaya (the largest NGO in Sri Lanka) facilitated the organisation of farmers in new settlements. However the NGO was criticised for becoming another contractor (roads and channels), deviating from its primary task of community development. The tank-based settlement component was seen as a break-through in planning methodology and effectively replicated under other IRDP's.

A3.1.3. The Anuradhapura Dry-zone Agriculture Project (ADZAP) Initiated in 1981, the Anuradhapura Dry-zone Agriculture Project (ADZAP) was another 'blue print' type program funded by the Asian Development Bank (ADB), the International Fund for Agricultural Development (IFAD) and the Government of Sri Lanka (GoSL) and project identification by the FAO investment center. The project was designed to assist chenna (shifting slash and burn) cultivators to become permanent farmer settlers. However it's highly politicised and bureaucratic implementation effectively bypassed the intended beneficiaries. The project aimed to permanently settle 4,000 families through establishment of a viable system of combined rainfed and irrigated farming integrated with livestock development. The program included extensive renovation of abandoned tanks with the Irrigation department and the DAS responsible upstream and downstream works respectively. Tank selection was to be by DAS recommendation or by formal request by of a group of chenna farmers around abandoned tanks. However most farmers lobbied for repair of existing tanks. Settlers were only identified after upstream works were completed. Political affiliation also became an unspecified but explicit selection criteria (14% of settlers). The final rate of settlement was 51%. Settlers closest to the tanks became the most reluctant to move to tank settlements due the existence of other income generating activities near the main road and increased reluctance to risk cultivation for several consecutive seasons post completion. This situation arose because of poor rains and technical standards (including high permeability of tank bunds and insufficient catchment). Downstream contractors progressively completed more downstream activities as farmer's efforts were considered to slow (machinery often being required to clear dense jungle). Confused demarcation of responsibility by the DAS and Irrigation Department slowed work further. These drawbacks also completely undermined the water management program that was to follow (as there was no water to manage!). The program has shown the lowest degree of success of all the programs discussed. Due to these problems and inappropriate budgetary appropriations, in 1994 the project was downsized considerably from 600 to 138 tanks, command area from 8,100 to 1,620 ha, settlers from 10.000 to 4,000 families and costs from US $14.5 to US $7.8 million. The project exemplified ineffective project management, design and implementation.

A3.2. <u>NGO Tank Rehabilitation Programs</u>

A3.2.1 The Freedom from Hunger campaign (FFHC) Although a public cooperation the FFHC has followed NGO strategy in carrying out it's village development activities, including peoples participation, labor intensive projects and helping to permanently settle chenna farmers through irrigation development. Never the less the program adopts yet another 'blueprint type approach'. Step type sluices were widely introduced which farmers complained were inefficient, bunds raised, spills repaired and feeder canals and anicuts installed for water diversion. The FFHC targeted tanks with existing settlement around them for renovation, so settling in problems did not arise (i.e. as in the AZDAP). To encourage farmer participation, draft and labour human labour were to be used in favour of mechanised plant. However this restriction had the effect of seriously slowing down many programs and was widely contravened – Fernando pers. comm..). FFHC sources state that by 1989 135 tanks had been repaired, 2,510 ha of paddy land developed, costing only US $2.7 million and benefiting 3,100 families. Vimaladaharma (1989) evaluated the program and observed that performance varies widely with the location of different tank clusters. In one large project area, the abbot of a local monastery was instrumental in selecting project beneficiaries and tanks. Although this lead to good adherence to project activities, this also resulted in costly selection of large number of very small tanks benefiting few families (often-personal relations) and wider neglect of landless groups. Problems have arisen with lack of tank maintenance due lack of funds made available or raised by water management organisations (formed for implementation of a tank restoration program). Whilst crop returns were good during in early years, following 1984 wide crop failures were reported under some 72 tanks for 4-5 seasons, resulting in reluctance of farmers to participate in maintenance work or even attend meetings. As an alternative to irrigated agriculture, homestead and highland (market) gardens have also been developed with project assistance for the excavation of (3m) dug wells for cultivation. This has been widely adopted (over 50% of farmers in one area with more farmers pooling funds to share one well). Highland market gardens have only been developed by a few farmers with the resources need to purchase a pump. This land consolidation component was significant success to the program, offering farmer increased risk management strategies. Also in many cases the formation of water management committees through which villagers are consulted has successfully increased farmers self-reliance and empowerment. Links with government organisations facilitated the granting of land permits to encroached farmers. Although farmers have been mobilised to participate more fully in construction work, their enrolment as labourers by the NGO rather than 'owners' has compromised the longer term likelihood of farmer involvement. Delays in construction and promised payments further reduced farmer enthusiasm. The FFHC has also been criticised for imposing a ‘top down’ romanticised version of a Sinhala dry zone village.

A3.2.2 The National development foundation (NDF) formed in 1979 is a true NGO funded by the Australian freedom from Hunger campaign (AFFHC). The magnitude of the NDF’s operation is small, but the success of its pilot programs has earned it wide repute (Dayaratne 1991). Stated objectives of the NDF were: to increase villagers confidence and subsequently self reliance, to help villagers to identify and mobilise their own resources, to understand and demand their rights and mobilise villagers through formation of peoples organisations. It has implemented six development projects in the following areas: tank renovation, bio-gas and integrated farming and an income generation project for women. Of special note was the involvement of women and youth and the identification of by beneficiaries of project outputs that suited their socio-economic requirements. The NGO’s irrigation program is a variant of the FFHC program but has followed a much more dynamic approach to farmer mobilisation for both system improvement and management. Tank rehabilitation has been undertaken in Kurunegala and the Puttalam Districts. Of 16 targeted tanks in Kurunegala, 10 were completed by 1989. One hundred and seventy two farm families had benefited and 88ha irrigated increasing the irrigable area of each tank by 10-25 percent. The tanks are small with command areas ranging from 2.8 to 15 ha. Farmer’s organisations have been established to manage operation and maintenance of the tanks and for equitable socio-economic benefits for families. Project costs over ten years were US $ 53,000, with US$3,275 being contributed by farmers themselves and the balance contributed by the NDF and the DAS. This equates to a pro rata cost of $10 per family or $608 per ha developed. The pilot program in Kurunegala has been extended to other tanks in this and Puttalam District. The NDF strategy was based on an assessment of the shortcomings of the FFHC campaign and has three unique features:

- Renovation is plan, designed and implemented with the participation of farmers.
- Manual labour as well as machinery was used for making the best use of available resources.
- Flexibility in planning and implementation was controlled by the beneficiaries (unlike the ‘blue print approaches outlined above).

After hand over to farmer the NDF and DAS gave necessary support for system management. The NDF organised relief credit from OXFAM for farmers to buy seed inputs after the disastrous drought year of 85/86 and loans were collected after the harvest. A few farmers who could not pay back the loans were not eligible for future loans. Farmers’ organisations have formed sub-committees for activities including water management; credit and marketing institutions and group funds established which have been used for annual maintenance work. These organisations have been apexed into an umbrella organisation known as the small farmer federation as a mechanism for continuous system organisation. A sense of community consciousness and responsibility has replaced a situation where beneficiaries themselves used to damage the bund for illegal water tapping. Average rice yields have increased from 805kg/ha to 2070kg/ha. The bethma system (see working paper 6) and culture of other field crops (OFCs) are practiced during the dryer *yala* season.

Appendix 4: Aquaculture potential in ancillary village water bodies.

A6.1: Potential for advanced fingerling production in agro-wells.

Water quality, key informant interviews and farm walks were used to assess the potential for advanced fingerling production in study villages. Such fingerlings might subsequently be used to stock seasonal tanks. Results of water quality analysis are included in Tables A5.1 and A5.2 (Appendix 5).

In DDW village 8 private agro-wells, 1 public open-well and 1 public tube well were identified. These were concentrated in the part of the village closest to the paddy command area, to exploit the elevated water table there. In PDW village 8 agro-wells were identified. Here the wells were more widely dispersed, but again located mostly within the command areas of the village tanks. Agro-wells varied in construction (cement, brick or unlined) and size (from 3-7m in width and 3m to 6m in depth).

In addition to irrigation, agro-wells are also widely used to augment domestic water supplies including human consumption. Only in three of the wells in PDW was water fit for consumption due to high salinity levels. Such wells were shared between 4-10 families, private owners usually giving access to their neighbours for domestic use. Most villagers used tube and small drinking wells provided by the government (at least two such units were available in each village). During drought episodes water is occasionally collected from neighbouring villages lower in the watershed with assured supplies.

Villagers in DDW reported highest salinity levels wells associated with poorly drained areas of the command area (confirmed by the taste of the water). Higher within the village, three farmers were using agro-wells to irrigate betel as a cash crop within their home gardens. Highly intolerant of salinity (Gunewardene. pers. comm.) this species is a good indicator in this respect. Turbidity levels were low in all wells investigated, reflecting the ground water source of their supply. Ground water pH levels varied between 6.8 and 7.8, an optimal range for all life stages of many freshwater species including tilapia and carp. Some farmers reported using wells for occasional storage of live fish caught from local tanks, again indicating basic standards of water quality. With good shelter from direct sunlight, water temperatures were on average 2-4oC lower than surface water bodies, a differential which may be useful if these wells were to be used for advanced fingerling production during the hotter dry season. In PDW all but one farmer reported perennial water supplies in their agro-wells whilst in DDW with it's poorer hydrological endowment, three out of eight farmers reported that some of their wells had come close to drying during drought years.

For advanced fingerling production, suitable wells would have to be strategically located in respect of good water availability (between July to December) and should not be used for drinking purposes (therefore saline wells[53] may prove particularly suitable). Natural productivity is low and wells would have to fertilised or supplementary feeds added. This would complement the use of such waters for irrigation. GTZ have successfully raised fingerlings in agro-wells for seasonal tank stocking purposes with good ability to protect stock from predation but report difficulty in harvesting fingerlings[54].

53 Common carp is able to tolerate salinity levels upto 16 ppt, whilst *O. mossambicus* is widely cultured in full-strength seawater. However much lower levels (2-3%) are required for successful breeding and survival to the fingerling stage.
54 Allegedly due to the uneven nature of floors encountered in trial agro-wells.

A6.2 Aquaculture potential in other village water bodies:

A brief assessment of aquaculture potential in the several other types of water body were identified in project villages follows:

Borrow Pits: These were of two principal types. Firstly extensive numbers of small ponds were created where soil had been excavated for brick production (an activity undertaken by many farmers). Some farmers used larger pits for supplementary irrigation of rainfed paddy. However, these ponds tended to be extremely seasonal (holding water for only 3-4 months in the more porous upland soils), shallow, turbid and prone to wide temperature fluctuation, making them poorly suited to aquaculture. A second type of borrow pit was created where material had been excavated for tank bund strengthening, or sand removed from tank beds for construction purposes. Pits located within the tank can create refuges for wild fish populations during the dry season. Conversely (depending on their location and size) by creating irregularities on the tank bed they could impede the harvesting of seasonal tanks using dragnets. Farmers reported that the area immediately beneath the tank bund is usually highly saline due to seepage. Borrow pits in these areas may be put into productive use for fingerling production. Such pits are often semi-seasonal or perennial due to the elevated water table beneath the tank. However such pits are widely used for watering animals during the dry season which may conflict with fish production.

Flooded Quarries: Quarries of various sizes were located in the rocky areas near the top of PDW and DDW watersheds, providing full-time or casual employment for landless villagers. Deeper quarries become more expensive to pump out during the rainy season resulting in the creation of several relatively deep (2-3m) and highly retentive water bodies with good potential for aquaculture Particularly in the PDW cascade. The NGO CARE have stocked one such quarry with tilapia on a trial basis. However as the natural productivity of this deep water body was low and no supplementary feed was added, poor growth rates were reported. Furthermore abandoned quarries are usually privately owned and access would have to be negotiated. Such easily protected environments may offer potential for advanced fingerling production, perhaps using cages.

Home garden ponds: These are effectively small homemade tanks used for supplementary irrigation, three of which were observed in home gardens of PDW village. With shallow depth and high irrigation demands, they are highly seasonal and therefore have poor potential for advanced fingerling production. However being homestead resources they may offer more suitable potential for rearing of ornamentals as an income generation activity for women. This could be achieved using cages located in refuges excavated in deeper areas of the tank.

Appendix 5: Results of water quality analyses.

Table A5.1: Water quality measurements for Pahala Diulwewa small tank cascade system.

Location	Date	Time	Weather	Turbidity (cm)	PH	MV	Water oC	Air oC	Comments
Groundwater sources:									
Agro-well (end of paddy Morankulam)	14/12	15.15	Sunny occ cloud	120 (green)	7.8	-59.7	29.9	31	Water table close to surface
Agro-well Sembugama home garden	19/12	11.00	Sunny	85	7.7	-48	26.8	29.2	Unlined agro-well irrigating paddy
Surface water sources:									
Quarry PDW	18/12	16.00	Sunny occ cloud	38 (silt/green)	7.55	36	31.5	32	Highly seasonal
Homestead tank PDW	18/12	18.00	Dusk	23 (silty)	6.5	14	29	29	Irrigating paddy and OFC's
Brick excavation pit PDW	18/12	17.30	Sunny occ cloud	18 (silty)	6.9	3	28.2	31	
Pahala Diulwewa	12/12	8.00	Night rains, cloudy	10 (silty)	6.85	8	28.5	36	3m to spill
Sembugama wewa	12/12	10.30	Bright, cloud	14 (silty)	6.45	32	28.5	32.8	30cm to spill, Salvinia, hypomia infested.
Agro-well (in front of PDW)	12/12	12.00	Bright, cloud	120	7.6	-35	29.8		
Ihala Diulwewa	12/12	17.00	Overcast	15 (silty)	7.5	-32	27.5	26	
Palugas wewa	14/12	12.00	Cumulus and sun	20 (silty)	6.8	12	31	30.4	Heavy night rains
Wayrankulamwewa	14/12	13.30	Sunny occ cloud	8 (silty)	6.8	11	32	31	
Morankulamwewa	14/12	15.00	Sunny occ cloud	18 (silty)	6.65	18.2	32.8	31	
Ulpathwewa	14/12	14.45	Sunny occ cloud	32 (silty)	6.9	3	33.2	29.5	
Uria Wewa – Near spill, E end of bund.	19/12	11.00	Sunny	70 (silt)	7.4	-34	29	31.4	1.2m to spill
Uria Wewa – Rocky pool seepage zone	19/12	11.00	Sunny	50 (silt)	7.74	-45.6	28.5	31.4	Contained keketiya (perennial indicator)

Table A5.2. Water quality in Danduwellawe small tank cascade system.

Location	Date	Time	Weather	Turbidity (cm)	pH	mV	Water oC	Air oC	Comments
Ground water sources									
Open earthen well – Private	20/12	17.30	Sunny Clear	82	7.94	-58	25	30.5	Low salinity (betel production)
Tube well – Public	20/12	17.45	Sunny Clear	NA	6.79	12.7	29		
Open earthen well – Private	21/12	19.00	Sunny Clear	76	7.75	47.2	27.6		Low salinity (betel production)
Standing water lower paddy	21/12	19.10	Sunny Clear	(silty)	6.85	6.5	27.8		
Agro well lower LH paddy	21/12	19.20	Sunny Clear	55	7.69	-48	29.1		
FO presidents well	21/12	19.30	Sunny Clear	84	7.34	-22	26.3		Salty taste
Surface water bodies									
Public well – Concrete @ foot of paddy	20/12	17.15	Sunny Clear	90	7.33	-22	27	31	
Mahawewa mid bund	21/12	15.25	Sunny Clear	45	6.78	2.9	29.3	29	30cm to spill (+Sandbagged 60cm)
Bandapu wewa spill	21/12	17.45	Sunny Clear	38	6.92	-5.6	29	30.5	
Mahawewa paddy drainage	21/12	13.30	Sunny Clear	(silty)	7	-1.2	30.6	33	
Ankendawewa (@ sluice)	21/12	14.00	Sunny Clear		7	-3	27.2		High salinity reported under bund
Stagnant water under Ankenda bund	21/12	14.10	Sunny Clear	Clear	7.4	-27	26.2		Containing wewa salaya
Top paddy field under Ankenda	21/12	14.30	Sunny Clear	-	7	-1	26.2		Fe and oily scum
Rathmale	22/12	18.00	Clear sky	37	6.34	7	30	33.5	Wewa salaya. RF paddy
Kumbukwewa	23/12	13.30	Sunny, cloud	71	8.57	-103	30.8	36.5	Lilly infestation
Kumbuk Top L paddy	23/12	13.45	Sunny, cloud	NA	7.77	-62.9	36.8	36	
Kumbuk L scrub	23/12	13.50	Sunny, cloud	-	8.17	-77.5	36.7		
Kumbuk central paddy	23/12	14.00	Sunny, cloud	-	7.7	-35.3	28.2		
Kumbuk drainage channel	23/12	14.10	Sunny, cloud	-	7.97	62	34.7		
Kumbuk lower L stagnant paddy	23/12	14.25	Sunny, cloud	(dark green)	9.14	140.8	37		Urea pellets visible
Kumbuk bottom R paddy	23/12	14.40	Sunny, cloud	-	8.59	101.9	34.8	36	
Kumbuk Lower drainage channel	23/12	14.55	Sunny, cloud	-	6.92	-5	29.4		
Kumbuk Lower R paddy	23/12	15.15	Sunny, cloud	-	8.2	-77	31		
Kumbuk bottom R field canal	23/12	15.30	Sunny, cloud	(silt)	8.1	-70.6	26.4		Stagnant, lillies and mimosa
Mahagalwewa tank	23/12	16.00	Sunny, cloud	69	7.16	15	31.5	31	
Mahagalwewa irrigation water @ sluice	23/12	16.20	Sunny, cloud	88	9.02	-132	28.9		High salinity reported under bund

Appendix 6: Statistical analysis of ranking and scoring results for water use priorities in Pahala Diulwewa and Danduwellawe villages.

A4.1a. Friedman test for Danduwellawe water resources

```
S = 25.73  DF = 5  P = 0.000
S = 27.93  DF = 5  P = 0.000 (adjusted for ties)

                   Est     Sum of
Treatment      N   Median   Ranks
Bathing       16    7.208    81.5
Bricks        16    1.208    36.0
Domestic      16    2.042    50.5
Fish          16    2.208    48.5
Irrigation    16    6.708    71.5
Livestock     16    2.375    48.0

Grand median  =    3.625
```

A4.1.b Mood median test for Pahala Diulwewa water resources

```
Chi-Square = 25.12   DF = 5   P = 0.000

                                        Individual 95.0% CIs
Criteria    N<= N> Median Q3-Q1 -----+---------+---------+---------+-
Bathing     13  15  5.50  4.75                (------+--)
Bricks      25   3  1.00  2.00  +-------)
Domestic    22   6  3.00  2.50       (----+
Fish        19   9  4.00  3.00            (----+--)
Irrigation  10  18  6.00  6.00       (------------------+---------)
Livestock   14  14  4.50  4.00         (----------+-)
                                -----+---------+---------+---------+-
                                    2.0       4.0       6.0       8.0
Overall median = 4.00
```

A4.2a. Friedman test for Pahala Diulwewa water resources

```
S = 27.75  DF = 5  P = 0.000
S = 29.34  DF = 5  P = 0.000 (adjusted for ties)
                   Est    Sum of
Criteria       N   Median   Ranks
Bathing       28    4.792   121.0
Bricks        28    1.625    62.0
Domestic      28    2.708    82.0
Fish          28    3.375    96.5
Irrigation    28    5.875   122.5
Livestock     28    4.375   104.0

Grand median  =    3.792
```

A4.2.b Mood median test for Danduwellawe water resources

```
Chi-Square = 25.90   DF = 5   P = 0.000
                                        Individual 95.0% CIs
Criteria    N<= N> Median Q3-Q1 +---------+---------+---------+------
Bathing     2    14  7.0   9.3               (---+--------------)
Bricks      13    3  1.0   2.7  (-+---)
Domestic    11    5  2.5   7.0  (-----+-----)
Fish        13    3  2.5   1.0       (+-)
Irrigation  5    11  8.0   8.0    (-----------------+-)
Livestock   10   6   2.5   4.0  (-----+---)
                                +---------+---------+---------+------
                               0.0       4.0       8.0      12.0
Overall median = 3.0
```

Appendix 7: Statistical analysis of ranking and scoring results for aquaculture constraints in Pahala Diulwewa and Danduwellawe villages.

1a. Friedman test for Pahala Diulwewa aquaculture constraints

```
S = 14.25  DF = 2  P = 0.001
S = 14.39  DF = 2  P = 0.001 (adjusted for ties)

Est    Sum of
Criteria      N   Median    Ranks
Poaching     26    4.000     54.0
Predatio     26    2.667     37.5
Water        26    5.333     64.5

Grand median  =    4.000
```

1b. Mood median test for Pahala Diulwewa aquaculture constraints

```
Chi-Square = 11.97   DF = 2   P = 0.003

Individual 95.0% CIs
Criteria   N<= N> Median Q3-Q1  ----+---------+---------+---------+--
Poaching   17  9  4.00   3.00                  +-----------)
Predation  22  4  2.00   2.00   +-----)
Water      10  16 5.50   2.00                  (-----------+---)
                                ----+---------+---------+---------+--
                                   2.4       3.6       4.8       6.0
Overall median = 4.00
```

2a. Friedman test for Danduwellawe aquaculture constraints

```
S = 12.29  DF = 2  P = 0.002

Est    Sum of
Criteria       N   Median    Ranks
Poaching       7    3.000     13.0
Predatiom      7    1.333      8.0
Water          7    7.667     21.0

Grand median  =    4.000
```

2b. Mood median test for Danduwellawe aquaculture constraints

```
Chi-Square = 14.13   DF = 2   P = 0.001

Individual 95.0% CIs
Criteria  N<=  N> Median Q3-Q1  -----+---------+---------+---------+-
Poaching  4    3   3.00   1.00          (+----)
Predation 7    0   1.00   1.00  +-----)
Water     0    7   7.00   1.00                             (+----)
                                -----+---------+---------+---------+-
                                    2.0       4.0       6.0       8.0
Overall median = 3.00
```

Appendix 8: 1:500,000 Survey map of DDW cascade

(Source GoSL Survey Dept).

Appendix 9: 1:500,000 Survey map of PDW cascade

(Source GoSL Survey Dept).