Mosaic of Traditional and Modern Agriculture Systems for Enhancing Resilience

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Abstract

There are many traditional agricultural production systems in Asia that have resulted not only in outstanding landscapes, maintenance of agricultural biodiversity, indigenous knowledge and resilient ecosystems development but also provided economic, environmental and social goods and services over thousands of years. With growing population and economic aspirations, many of these systems are being replaced by modern agriculture systems that are designed for efficiency and large-scale development. However, there is also a growing realization that we should in some form preserve these valuable repositories of indigenous knowledge for climate change adaptation, biodiversity conservation and land management and the rich culture they spawned. Different approaches such as Culturural Heritage Systems of UNESCO, or the Globally Important Agriculture Heritage Systems of FAO attempt to preserve and showcase representative production sites from these systems. However, they cannot be upscaled to cover the vast populations still engaged in them. In this paper we investigate the feasibility of fusing the traditional and the modern systems through building mosaics of traditional and new systems.

The Deduru Oya reservoir which was commissioned in 2014 is primarily planned to improve the livelihood of farmers in parts of the North-Western Province of Sri Lanka by increasing the productivity of its land and water resources by regulating and diverting water to irrigation systems through two main canals in both river banks. . The left bank canal supplement water needs for paddy cultivations from existing ancient rainfed small reservoir based irrigation systems. The right bank canal is transbasin canal coveying excess water from the reservoir to adjacent Mee oya basin. The Deduru Oya irrigation project provides an ideal ground for research and experimentation of integrating modern irrigation and ancient irrigation systems to improve cropping intensity and resilience.

The simulation carried out for past ten years reveal that the Deduru Oya reservoir project which has planned to operate LB canal irrigation management incorporating the existing small irrigation tanks will be able to supply the water demand for LB development area for paddy cultivation without failure. While the modern system can adequately meet the irrigation demand, the integration of existing distributed small tanks provides resilience for extreme drought conditions and the much-needed macro-micro scale integration with autonomy at micro scale.

1. Introduction

Asia is home to a number of traditional agricultural landscapes that have withstood climate variability and varied societal changes for over thousand years. These systems have resulted not only in outstanding landscapes, maintenance of agricultural biodiversity, indigenous knowledge and resilient ecosystems development, but, above all, in the sustained provision of economic, environmental and social goods and services. In addition to the social and environmental importance of these systems, they are valuable repositories of indigenous knowledge for climate change adaptation, biodiversity conservation and land management. The ancient irrigation systems in the dry-zone in Sri Lanka are an example of such sustainable agriculture systems, which helps the rice agriculture adapt to the variable and seasonal conditions of Monsoon rainfall where rainfall is concentrated in 3 months of the year. In response to this climatic conditions irrigation systems consisting of large number of interconnected reservoirs (*weva* or tanks) evolved during the period from 3 century B.C. to 12 century A.D. It is widely accepted that the ancient irrigation system in the dry-zone of Sri Lanka was largely developed during the period up to 12th century. The system faced a decline from 13th century to 19th century (Panabokke, 1999) due to numerous reasons including poor soil conditions, malaria epidemic, political instability, etc., although the system did not completely collapse. These systems still function as a crucial element in agricultural sector of the dry zone supporting a large farmer population. They also constitute one of the richest sources of wetland biodiversity in the country. However, the productivity of such systems is not high enough now to support the growing population and aspirations of modern day lifestyles by their agricultural output alone.

Now, modern irrigation schemes have replaced much of the old tank based systems. These modern irrigation schemes with centralized management are highly productive and are designed to efficiently cater to highdemands of present day populations and economic growth. However, these systems are highly optimized and run the risk of failure with changes to existing climate and ecosystems state. In addition, much had been lost in social harmony, human-nature co-existence and system resilience. In the present day context, farmers are organized into legally recognized autonomous organizations. Each irrigation scheme has a Project Management Committee (PMC) consisting of representatives of the Farmer Organizations and the government agencies concerned with irrigated agriculture and water allocation. Water allocation is discussed and decided through meetings at PMC. This system does not make farmers an integral part of the whole system.

There have been a number of large-scale development projects involving reservoirs and diversions providing irrigation to the dry-zone recently (most rapid developments during 70s and 80s), making it difficult to ascertain their long-term impact on ecosystems, biodiversity and man-made habitats associated with tanks. The ancient systems could provide valuable insights to make them sustainable and attractive and be very useful in the quest of various development alternatives, especially for sustainable green development pursuits. How can the characteristics of ancient systems be incorporated in today's infrastructure management systems? What lessons can be leant from the past to design community based management system supported by a regional layer that address macro level management requiring higher level of technical competency followed by central organizational oversight? How can we incorporate the lessons from these systems to integrate reservoirs to local communities, not only as efficient water storage and management systems as designed today, but also a host of other services for bio-diversity, social harmony, aesthetic beauty and cultural activities? This papers investigates the viability of a mosaic system consisting of modern and ancient systems to improve overall resilience of the system and improve livelihoods to all farmers through the increases in productivity.

2. Ancient Irrigation Systems of Sri Lanka

2.1 Description of the system

The ancient irrigation systems in Sri Lanka were perfected through consistent improvement and construction over 1600 years and cover most of the north-central zone of Sri Lanka with intricate networks of small to gigantic reservoirs (tanks) that numbered around 15,000 connected through a series of feeder canals that brought water for yearlong rice cultivation in the dry zone. Figure 1 shows a distribution of some of the larger tanks in the North Centrap Province of Sri Lanka. Highly sophisticated engineering skills have been developed with the evolution of the systems that include first large scale sluice gates and near zero gradient irrigation canals. Maintenance of the systems also requires a high level of understanding of hydrology and hydraulics as applied to large systems. This hydraulic civilization has successfully bridged micro and macro systems where small village reservoirs were linked up with massive reservoirs in intricate hydraulic systems. Brohier (1934, 1937a) identified that there is a chain like structure in organization of small tanks in Sri Lanka and their relationship with large ancient reservoirs and waterways. Madduma Bandara (1994) coined the term *cascades* to identify this pattern where water from upstream tanks was successively stored and released to those of downstream. These small cascades are linked to large reservoirs and giant feeder canals to form extremely complex large irrigation systems.

Figure 1. Shapes of various sizes in blue color show the distribution of large number of irrigation tanks in the North Central Province of Sri Lanka (source: google Maps)

Brohier (1934, 1937) explained the evolution of the tank systems as starting from a stage where rainwater tanks were built and water bailed out, followed by small tanks and canals followed by the 3rd stage where large reservoirs were built by submerging some small tanks. The final or the fourth stage was where the weirs across major streams were built and large-scale canals such as Yoda Ela were built to enable trans-boundary water distribution.

Mendis (1986) presented an alternate view proposing that rain fed farming to irrigated farming evolved through the construction of river diversion works, followed by invention of sluice and construction of small, medium and large reservoirs, first across non-perennial water ways and finally large reservoirs across perennial services. This view also helps to appreciate the collection and use of rainfall runoff in-between source reservoirs by single bank contour canals of the ancient irrigation system.

The technical breakthrough that enabled the construction of large irrigation systems in Sri Lanka is the invention of the ‘valve tower’ or the ‘valve-pit’. Sir Henry Parker, a British Engineer with the irrigation department who was entrusted with rehabilitation of ancient irrigation systems in mid 1800 describe the skills and inventions that went to the development of ancient tanks as follows. *“It may be assumed, that the formation of all reservoirs of a class with embankments much higher than those of simple village tasks was originally due to the constructive genius of the Sinhalese; they were the first inventors of* *the valve-pit, more than 2100 years ago.(Parker, 1909)".* This construction made it possible to use a single sluice gate to distribute water to paddy fields at any reservoir water level. However, it cannot accommodate high volumes associated with large reservoirs. The 'bisokotuwa' has been developed for this purpose (Avsadahamy, 2003). Sir Henry Parker (1909) describes the still intact bisokotuwa of 'Pawatikulam tank', which had performed its duties continuously for over 2100 years.

The salient feature of irrigation system is the tanks cascades in which water from upstream tanks are successively stored in those downstream in a catchment (Figue 2). Each cascade has a number of tank-village units each with a small reservation catchment, the reservoir, a strip of trees downstream of the reservoir that act as a wind breaking barrier, paddy fields, and the village (Figure 3). The small tank cascades are then linked to large reservoirs and giant feeder canals to form extremely complex large irrigation systems. The system of tanks, paddy fields and canals are so well integrated and inter woven with the natural environment, it is difficult to identify tank systems as man made structures.

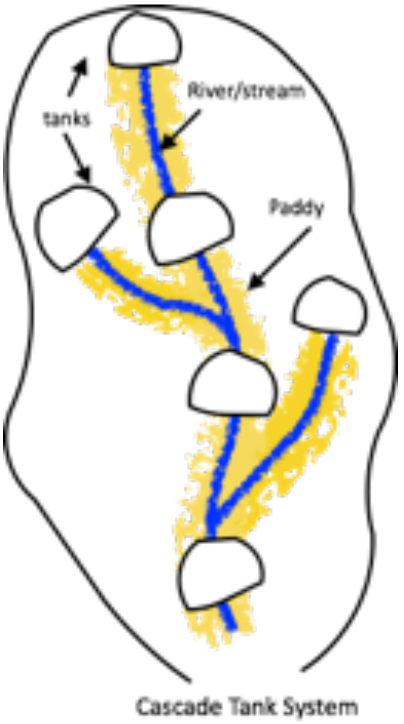
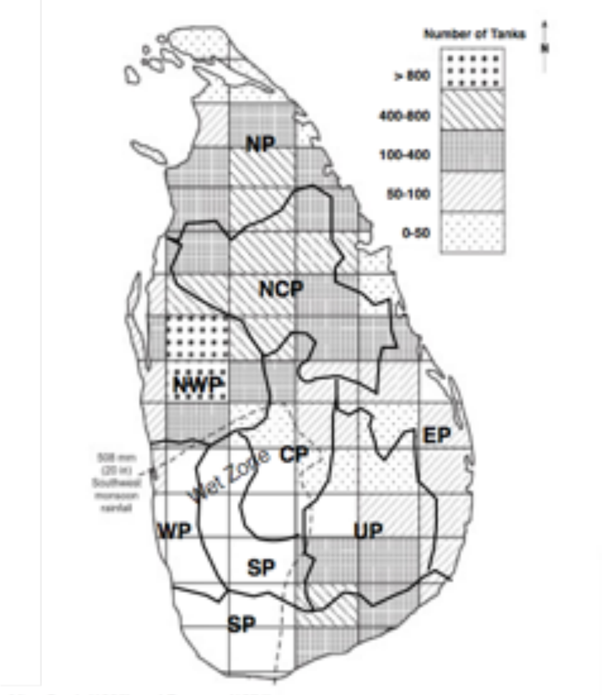


Figure 2 Schematic respresentation of a tank cascade.

Figure 3. Schematic diagram of the layout of a village-tank unit

One of the remarkable features of the tank systems is their sheer density. Panabokke et. al., (2002) have identified slightly over 15,000 ancient irrigation tanks as shown in figure 4 of which about a half are still functioning. Each grid in the figure represents one topo sheet covering 950 km^2. The distribution shows the highest tank density to be in the North Western Province (NWP) at about one tank per each 1.2 km^2 while the lowest tank density is recorded in the Eastern Province (EP) at one tank per 12 km^2. For NC, NCP and SP provinces the average density is found to be around one tank per 2.6 km^2. An analysis of tank distribution by each province shows that it is a function of both rainfall and the population density. While it is not clear if all the tanks were in operation at any given time, hydrological studies assuming typical runoff coefficients of small tank catchments at 0.15 - .3 have shown that the catchment areas are not adequate to supply inflows to all the tanks to irrigate the command areas under them. For example, Sakthivadivel et al, (1966) have observed that only 104 cascaded out of 240 cascades had adequate catchment area to supply adequate runoff that would ensure at least a 75% cropping intensity.



After Cook (1935) and Domros (1974)

Figure 4. Distribution of ancient irrigation tanks in Sri Lanka (source: Panabokke et. al, (2002)

2.2 Goods and Services Provided by the System

While the primary service provided by the tanks was the storage of rainfall to enable yearlong rice growing with two seasonal crops, the tanks provided a number of other services. They made the microclimate pleasant and cool, enabled bio and agro diversity. The tanks also served as the common bathing place for the village and the meeting point for the village described in figures 5-8.

Some of the tanks termed *Olagama* tanks were operated for recharging and stabilizing ground water, another type of tanks termed *Kuluwewa* have been constructed for sediment control, and *Godawala* were used as water holes that provided access to village cattle and

Figure 5. An ancient irrigation tank

Figure 6. Embankment of a tank

Figure 7 Irrigation canals

Figure 8 Bathing and socializing at a tank

animals, birds, etc., following the Buddhist teaching that we are not 'owners' but are the 'custodians' of common resources to which all living entities have equal rights.

Most importantly the independence provided the ancient tanks through to each village has paved the way for a unique decentralized social system in Sri Lanka, where farmers had the highest social rank. The development of tank irrigation system was a crucial element in the social organization and cultural traditions in the dry-zone. Numerous villages in dry zone are having names synonymous with the name of the village tank. The highly distributed nature of this 'water resource' and the sheer number density had no doubt contributed to the shaping of the social structures of people that built, managed and reaped benefits of them. The nature of the system encourages a much decentralized mode of water governance at the same time emphasizing the importance of inter-relationships and co-operation at larger scales.

Sri Lanka's low land also features a number of very large historical reservoirs that are believed to be the products of a centralized state bureaucracy. When the states that supported them collapsed (after 13th century), these works were also ruined. However, the village tanks did not perish because they were constructed, managed and maintained by the respective villagers. It is believed that there had been a sophisticated system of shared responsibility and social equity developed around the village tank system. Until the colonial government initiated irrigation department in 1860s in fact, the management of village tanks completely remained on the hands of the locals.

Sri Lanka's ancient history provides several examples where the state's authority was effectively challenged and sometimes overrun by the common opinion. In addition to cultural and religious factors, historians increasingly see a contribution from the very decentralized and independent nature of the village tanks systems towards the freedom of thinking. In fact, in the ancient history of Sri Lanka (particularly the early period of the 2nd millennium) there are occasions showing a competition between the independent, self-sufficient villages and the desire of central authorities to consolidate them in to state. Study of the history of Sri Lanka does not reveal evidence that a centralized bureaucracy ever even existed to run the country's irrigation works (Leach, 1959). The necessary maintenance work was organized by the villagers themselves: there was never a centralized bureaucracy to direct such work or to ensure that it was carried out. (Goldsmith and Hildyard, 1984). It is reasonable to assume that the social system organized around the village tanks in ancient Sri Lanka was significantly different from the feudalism in the medieval Europe and many others elsewhere in the world. Understanding this unique and sustainable way of life is also as important as the scientific, economical and ecological aspects of the ancient tanks systems.

2.3 Threats and Challenges

During the early 19th century the colonial government of the time did not allow the people to restore or repair their sluices or tanks, but later identified the importance of the tank system for the human livelihood in the dry-zone (Levers 1890). However, the poor knowledge on the function of the systems had lead to either ignorance or unplanned disruption of the ancient tank systems during large-scale irrigation development projects during 20th century. As the centralized large-scale schemes were considered to be more efficient than the decentralized small systems, a number of small tank cascades were replaced by large reservoirs and high capacity feeder channels.

However the modern development has not been able to capture the harmony between local and regional hydrological characteristics that the older small cascade tank systems and ancient large reservoirs could capture so admirably. One of the examples is the function of the giant feeder canals, which Brohier (1937b) describes in relation to one such canal, as "*The Jayaganga, indeed an ingenious memorial of ancient irrigation, which was undoubtedly designed to serve as a combined irrigation and water supply canal, was not entirely dependent on its feeder reservoir, Kalaweva, for the water it carried. The length of the bund between Kalaweva and Anuradhapura intercepted all the drainage from the high ground to the east which otherwise would have run to waste. Thus the Jayaganga adapted itself to a wide field of irrigation by feeding little village tanks in each subsidiary valley, which lay below its bund. Not infrequently it fed a chain of village tanks down these valleys – the tank lower down receiving the overflow from the tank higher up on each chain*". The

Figure 9. A modern feeder canal with paved embankments on both side and steep gradient.

Figure 10. An ancient feeder canal close to the modern one in figure 9, witn a single bank that trap the local inflow and slow velocity as it is a contour canal that retain a large command area.

photo 6 shows a modern feeder canal that is entirely dependent on the feeder reservoir as it shuts off the valley drainage by the high embankments on both sides of the canal. In contrast the Photo 7 shows the ancient feeder canal, which is now located a few tens of meters below the modern construction, having one embankment open to catch the runoff and following the contour lines that result in very low velocity and minimum loss of command area. The multifaceted functionality of ancient systems has given rise to a renewed interest to scientifically understand the function of the tank systems in recent times. The ancient irrigation systems have been developed and constructed over 1600 years, and the collective wisdom of those long years, in addition to the natural selection process that must have eliminated the unsustainable practices should be embedded in the remaining systems. It is therefore, very important to rehabilitate and scientifically understand their functions and services adequately.

The Minneriya Tank, built in 227 A.D. with a circumference of 32 km with a capacity of 136 million cubic meters has been irrigating farms un-interrupted till present. The operation and maintenance know-how of such reservoirs were lost in the wars in when those entrusted with the maintenance of large tanks were killed and the governance sysems collapsed in 16th and 17th centuries. What ever remained was lost during the colonization and modernization of the last couple of centuries. It is a great challenge to search, un-cover and combine whatever knowledge that remain with isolated individuals to understand the ecological resilience of this great heritage.

3. Methodology

Resilience building needs to be viewed holistically considering various challenges and identifying approaches that build resilience in various sectors. In this research we adopt the frame work shown in Figure 11, (Herath, 2011) where the global change challenges such as climate change, land cover change, population increase, economic growth targets and globalization are viewed as drivers that bring about challenges. They are to be addressed by strengthening ecological, social and economic resilience of the system. In this research we addressed the (a) ecological resilience through the integrated water resources management in a Mosaic of 'old' and 'new' water infrastructure, the (b) social resilience through developing a framework for farmer associations at village level to interact with centralised water management authorities for basin wide resource allocation and management, and (c) economic resilience through and analysis of economic benefits of crop diversification.

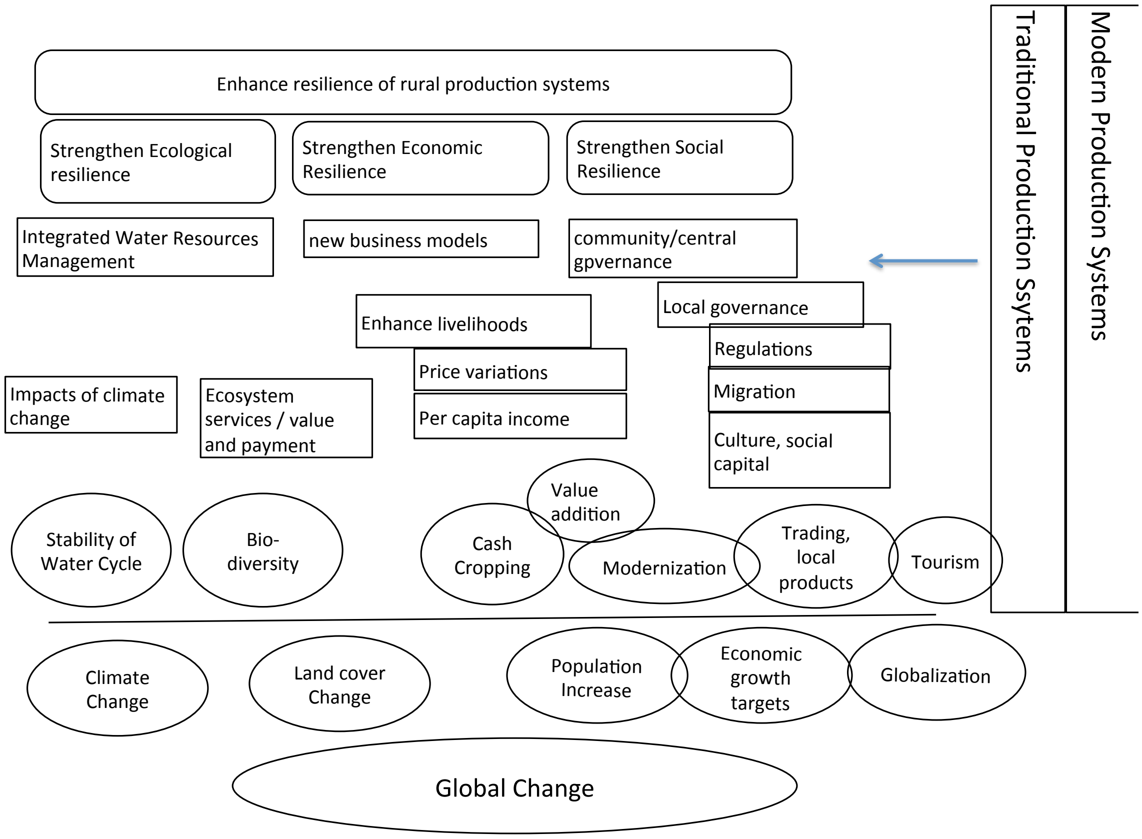


Figure 11 Framework for developing strategies for building resilence in rural production systems.

In this paper only the results of section (a) and (b) are discussed as they are directly relevant to the 'Mosiac' concept.

3.1 Modeling water allocation in ancient and modern reservoir system

For the study Deduru Oya basin is selected as a new reservoir was being constructed in the basin, which is the sixth largest river basin in Sri Lanka. The basin also has the largest number of village tanks in the country. It has been decided that the left bank (LB) canal of the new reservoir would feed the ancient irrigation tanks in addition to directly providing irrigation to new land. The command area under ancient tanks on the left bank side are often affected by prolonged drougts and in some years farmers cannot even cultivate a single crop due to lack of adequate water in the tanks. The supply of water to the tanks some times take the form of drop-in take-out pattern where the LB canal from the main reservoir would feed a ancient tank from one side and then pick up from the other side. On other occasions, distribution canals will feed the tanks. At first a lumped system was analysed where number of adjacent tanks were combined to form tank groups for the purpose of analysis. However, due to the varied storage levels and the water receiving mechanisms it became clear that individual village tanks need to be modeled with the central reservoir for the purpose of derving optimal water allocation plans and identifying vulnerable points in the system. Therefore the whole system comprising of 145 distribution nodes were modeled to derive water allocation planning and assessing water resources. In order to assess the effectiveness of the stand alone and combined systems the following scenarios were simulated.

- Ancient village tanks only under normal climatological conditions.
- New reservoir only under normal climatological conditions.
- New reservoir only under dry weather conditions.
- New reservoir and Ancient village tanks under dry conditions.

Inflows to each ancient reservoir were modeled independently and the combined system under the irrigation demand was modeled with WEAP model to estimate water allocation quantities.

3.2 Water management in ancient and modern reservoir system

Water management in the combined system requires special attention. Once the water allocation determines the water issues to and from each village reservoir and the LB canal, careful consideration is needed in water management according to allocation plan and available resources. Under normal operations, the irrigation department will be responsible for issuing water at each distribution canals to be managed by farmer associations. In the ancient reservoirs, an appointed villager is responsible to allocate water according to the norms adopted by the community. These village level operations are only concerned with the management of water within the command area of their village tank. There is no water optimization among the tanks in a cascade. The downsteam tanks would depend on the spillage from upstream, inflow from their tank catchment, seepage from upstream and the return flows from the paddy upstream paddy fields to supplement the water in their tanks. However, once the LB canal is directly linked to a particular tank, it is important that they understand that they are responsible for ensuring sufficient flow to cascades downstream of the LB canal. This means the farmers have to be trained in quantification and managing the amount of water they are allowed to use. If these measures are not implemented, the irrigation department would have to take over the water issue from the ancient tanks as well to ensure water management is carried out according to the allocation plan. However, that would defeat the purpose of reviving the ancient tanks system. Therefore we have studied different types of water allocation systems and concluded the bulkwater allocation system in Mahaweli System H is an appropriate water management system for Deduru Oya scheme. A reserher spent nearly two months in the fileld discussing with farmers and farmer assoications to identify principles and measures required to be adopted in the basin for the water management of the mosaic system.

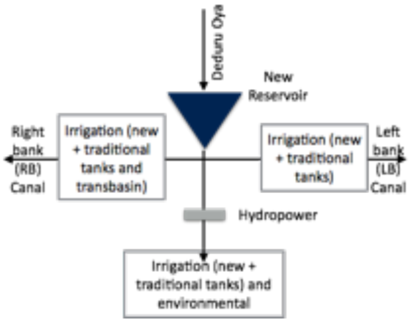
4. Water Allocation in the Mosaic System

4.1 Deduru Oya Project Description

Recently, government of Sri Lanka has been emphasizing on agricultural development through the renovation of ancient irrigation works (Godaliyadda et al, 1998). Many irrigation systems have been either rehabilitated or being rehabilitated to ensure reliable water supplies to farmlands. Deduru Oya Reservoir project is one of the several under-rehabilitation projects. Detailed description of the Deduru Oya project, the hydrology and the inflows are descrined in a separate chapter of this volume. Only a brief description is provided here that is relevant to the water allocation modeling study.

Potential water resources in the basin are the direct rainfall, stream flow, surface (tanks) water storage and groundwater storage. Quantity of water availability varies spatially and temporally across the basin, significantly. There are very low flows in the stream usually during January, February, July and August months. Surface water resources in Deduru Oya are very much influenced by the climatic pattern and steep terrain in the upper catchment. The water available from the rainfall and collected in the existing tanks is not sufficient for two season cultivation. Seventy percent of annual rainfall in the region flows to ocean without being utilized in any way to serve needs of the local population. As a result, an optimal level of agricultural development has not been achieved.

Deduru Oya reservoir project is aimed to exploit the Deduru Oya water resources in improving the cropping intensity of existing agricultural lands under tank irrigation systems and developing new agricultural lands in the Mee Oya and the Deduru Oya basins to enhanc productivity. The project, on completion, with about 45 km long left bank main canal, 33 km long right bank transbasin canal and 27 km long branch canals will be able to irrigate over 11,115 ha (Table 1). The Project envisages construction of a 75 MCM



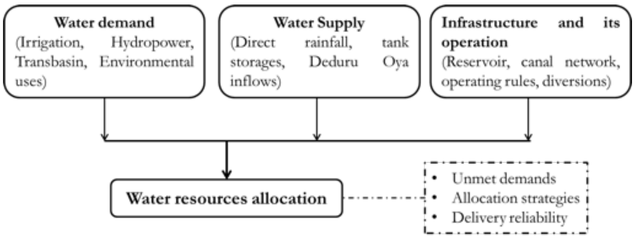


Figure 13: Schematic of water supply and demand management

Figure 12 Schematic representation of Deduru Oya

reservoir with two sluices and eight radial gated spillways. The 2.4 km long earthen dam with full supply level of 70m above mean sea level will result inundation of 2000 ha land.

Table 1: Details of existing and proposed irrigation area under Deduru Oya Reservoir Project

Components	Irrigable area (ha)		
	Exsisting	Proposed	Total
Deduru Oya basin			
LB canal	2400	300	2700
Ridibendi Ella (D/S)	2400	600	3000
RB canal	1000	300	1300
Mee Oya basin using transbasin canal			
Iginimitiya	2640	0	2640
Radavi Bendi ela	210	400	610
Tabbowa tank	865	0	865
Total	9515	1600	11115

4.2 Environmental flow requirement

There is an increasing awareness of the need to release a minimum amount of water along a river to ensure the continued functioning of ecological process that provide much needed goods and services for downstream community as well as maintenance of biodiversity. Water, which is allocated and made available for maintaining ecological processes in a desirable state, is referred as the instream flow requirement, environmental flows, or environmental flow requirement. The allocation of water to satisfy environmental uses initially developed out of the need to release from dams minimum flows to ensure the survival of often a single aquatic species with high economic value. However, the provision of environmental flows that attempt to preserve natural flow characteristics such as timing, frequency, duration and magnitude of flows is considered important for the sustenance of fresh water ecosystems, since the flow regime is one of the major drives of ecological processes on a river. The practice of environmental flow requirement began as a commitment to ensuring a 'minimum flow' in the river, often fixed at 10% of mean annual runoff (World Commission on Dams, 2000). In this study, a minimum of 10% normal climatic year monthly river discharge has been ensured as environmental flow requirement for testing the water supply and management scenarios.

4.3 Irrigation water requirement

Calculation of irrigation water requirement needs crop, climate and soil datasets of the study area. Paddy (rice) is the main crop in the region accounting for most of the agricultural water demand. The climatic data includes reference evapotranspiration and rainfall. This study used the Cropwat model by FAO Land and Water Development Division for calculation of irrigation water requirement. The irrigation water requirement is defined as the difference between the crop water requirements and the effective precipitation (FAO, 1998). The primary objective of irrigation is to apply water to maintain crop evapotranspiration when precipitation is insufficient. Crop water requirement (CWR) refers to the amount of water required to compensate for the evapotranspiration loss from the cropped field. Estimation of the crop CWR is derived from crop evapotranspiration (crop water use), which is the product of the reference evapotranspiration (ETo) and the crop coefficient (Kc). The climatic data (ETo and rainfall) used for the calculations of IWR is based on Batalagoda station (Dharmarathna et al., 2011). Information on soil data is based on textural properties ISRIC-WISE global soil data (Batjes, 2008). The soils in the area are predominantly coarse textured, ranging from loamy to sandy loam in the surface horizons and from sandy loam to clay in the subsurface horizon. Red loamy soil type was assumed for the study area after reviewing textural information and 'preliminary assessment of surface water resources' by Wickramaarachchi (2004). Soil parameters are based on the standard values for Red loamy soil in the Cropwat model sample data sets. Calculation of IWR at scheme level for a given year is the sum of individual CWR calculated for each irrigated crop. Multiple cropping (several cropping periods per year) is thus automatically taken into account by separately computing CWR for each cropping period. Calculation of scheme IWR has been illustrated through Tables 2 to 6. Annual irrigation water requirement with system efficiency 0.5 (application efficiency 0.7 × conveyance efficacy 0.7) and 0.6 was found to be 24354 and 20295 cubic meter per hectare respectively. Monthly variation of the irrigation water is shown in Figure 14. Total irrigation demands in left, right and downstream side is presented in Table 8.

For table 3: Monthly variation of rainfall and reference evapotranspiration at Batalagoda climate station

Month	Total rainfall (P), mm	Effective rainfall, (0.8*P) mm	ET_o, mm/day)
Jan	42.9	34.3	4.5
Feb	26.9	21.5	5.1
Mar	95.5	76.4	5.7
Apr	180.9	144.7	5.7
May	45.4	36.3	6.2
Jun	34.0	27.2	6.4
Jul	25.2	20.2	6.0
Aug	31.2	25.0	6.8
Sep	56.5	45.2	6.4
Oct	200.1	160.1	5.0
Nov	207.8	166.2	4.1
Dec	105.4	84.3	4.1

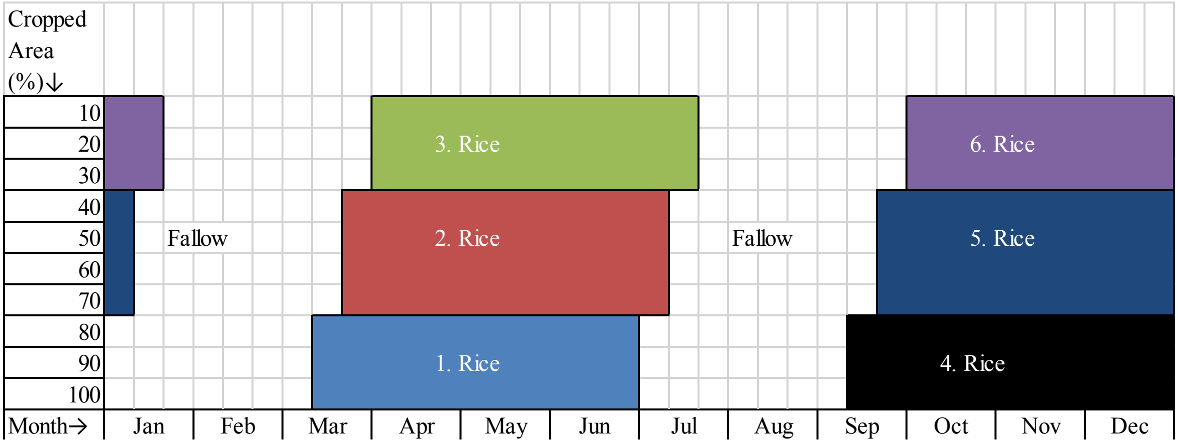
Table 4: Details on different stages of rice crop growth

Crop name: Rice			Transplant date:			Harvest date:		
Stage	nursery	Land preparation		Growth stage				total
		total	puddling	initial	develop	mid	late	
Length (days)	25	20	5	20	30	30	25	130
Crop coeff, Kc (dry)	0.70	0.30		0.50	1.05		0.70	
Crop coeff, Kc (wet)	1.05	1.05		1.10	1.20		1.05	
Rooting depth (m)				0.10			0.60	
Puddling depth (m)			0.40					
Nursery area (%)	10.00							
Critical depletion	0.20			0.20		0.20	0.20	
Yield response factor				1.00	1.09	1.32	0.50	1.10
Crop height (m)						1.00		

Table 5: Input parameters for Red Loamy soil

Soil parameters	**Values**	**Units**
Total available soil moisture	180	mm/meter
Maximum rain infiltration rate	30	mm/day
Maximum rooting depth	900	centimeters
Initial soil moisture depletion	0	%
Initial available soil moisture	180	mm/meter
Drainable porosity	10	%
Critical depletion for puddle cracking	0.6	fraction
Maximum percolation rate after puddling	3.1	mm/day
Water availability at planting	5	mm WD
Maximum waterdepth	120	mm

Table 6: Cropping pattern for a year



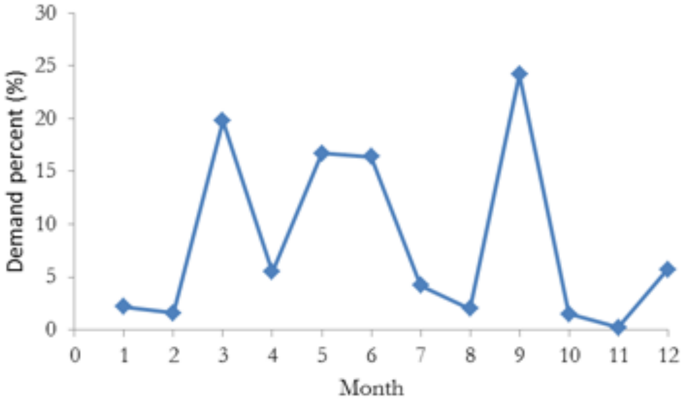


Figure 14 Monthly variation of the irrigation water requirements

Table 7: Scheme irrigation water requirements

Months→	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Precipitation deficit												
1. Rice	0	65.5	261.9	57.8	206.8	178.1	0	0	0	0	0	0
2. Rice	0	0.6	275.6	50.4	204.2	207.9	41.2	0	0	0	0	0
3. Rice	0	0	174.5	96	197.3	213.3	113.2	0	0	0	0	0
4. Rice	0	0	0	0	0	0	0	78.8	311	22.7	2.2	54.9
5. Rice	19	0	0	0	0	0	0	0.8	323.6	19.1	2.2	74.8
6. Rice	62.4	0	0	0	0	0	0	0	205.8	15.5	2.2	78.2
Net scheme irr.req.												
in mm/day	0.8	0.7	7.8	2.2	6.5	6.7	1.6	0.8	9.5	0.6	0.1	2.3
in mm/month	26.3	19.9	241.2	66.3	202.9	200.6	50.4	24	284.5	19.1	2.2	69.9
in l/s/h	0.1	0.08	0.9	0.26	0.76	0.77	0.19	0.09	1.1	0.07	0.01	0.26
Irrigated area (% of total area)	70	70	100	100	100	100	70	70	100	100	100	100
Irr.req. for actual area (l/s/h)	0.14	0.12	0.9	0.26	0.76	0.77	0.27	0.13	1.1	0.07	0.01	0.26

Table 8: Total irrigation water requirements in left, right and downstream schemes

	Irrigation water requirement					
Month	m3/ha	Monthly variation (%)	Left bank for 2700 ha in m3/s	Right bank for 1300 ha inside Deduru basin in m3/s	Transbasin to Mee Oya basin for 4115 ha in m3/s	Downstream for 3000 ha in m3/s
Jan	536	2.2	0.540323	0.260155	0.8234916	0.60035842
Feb	387	1.6	0.43192	0.207961	0.6582775	0.47991071
Mar	4821	19.8	4.859879	2.339942	7.4068156	5.39986559
Apr	1348	5.5	1.404167	0.67608	2.140054	1.56018519
May	4071	16.7	4.103831	1.975918	6.2545419	4.55981183
Jun	3992	16.4	4.158333	2.00216	6.337608	4.62037037
Jul	1018	4.2	1.02621	0.494101	1.5640196	1.14023297
Aug	482	2	0.485887	0.233946	0.7405279	0.53987455
Sep	5892	24.2	6.1375	2.955093	9.3540046	6.81944444
Oct	363	1.5	0.365927	0.176187	0.5577005	0.40658602
Nov	52	0.2	0.054167	0.02608	0.082554	0.06018519
Dec	1393	5.7	1.404234	0.676113	2.1401564	1.56025986

4.4 Inflows estimation for ancient tanks

SimHyd, a conceptual rainfall runoff model, was used to simulate daily inflows towards to the left bank ancient tanks (Figure 15). SimHyd model has been extensively used for various applications (Podger, 2004; Chiew and Siriwardena, 2005). The SymHyd model is a component of the rainfall-runoff library (RRL) produced by Cooperative Research Centre for Catchment Hydrology, Australia. The structure of SimHyd and the algorithms describing water movement into and out of the storages are shown in Figure 16. In this model, daily rainfall first fills the interception store, which is emptied each day by evaporation. The excess rainfall is then subjected to an infiltration function that determines the infiltration capacity. The excess rainfall that exceeds the infiltration capacity becomes infiltration excess runoff. Moisture that infiltrates is subjected to a soil moisture function which diverts the water to the stream (interflow), groundwater store (recharge) and soil moisture store.

Calibration and validation of the rainfall-runoff model was carried out using hydroclimatic data at Tittawela tank. The Tittawela tank has drainage area of 2.95 km^2. Calibration of the model was tested over the period 1995/05/01 to 1995/12/31. The model performance is illustrated by comparing observed daily and simulated daily stream flow values over the period 1996/01/01 to 1997/03/31 as shown in Figure 16. The calibrated/validated rainfall-runoff model enabled generation of daily inflows to the ancient tanks using respective drainage area and climatic data. Thiessen polygon method has been used for estimating coverage areas of different rainfall stations in left bank canal side (Figure 18). The model possesses both manual as well as automatic optimization facilities for parameter calibration. In this study, SCE-UA (shuffled complex evolution university of Arizona) option was selected for carrying automatic optimization. The Nash-Sutcliffe coefficient (*E*) of efficiency was used as a measure of the model performance (Nash and Sutcliffe, 1970). The *E* value describes agreement between all modeled (Q_m) and observed (Q_o) runoffs, with *E*=1.0 indicating that all the modeled runoffs are same as the recorded runoffs (Equation 1). The Nash Sutcliffe coefficient for the calibration and validation was found as 0.93 and 0.69 respectively.

$$E = 1 - \frac{\sum_{t=1}^{T}\left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T}\left(Q_o^t - \bar{Q}_o\right)^2} \qquad (1)$$

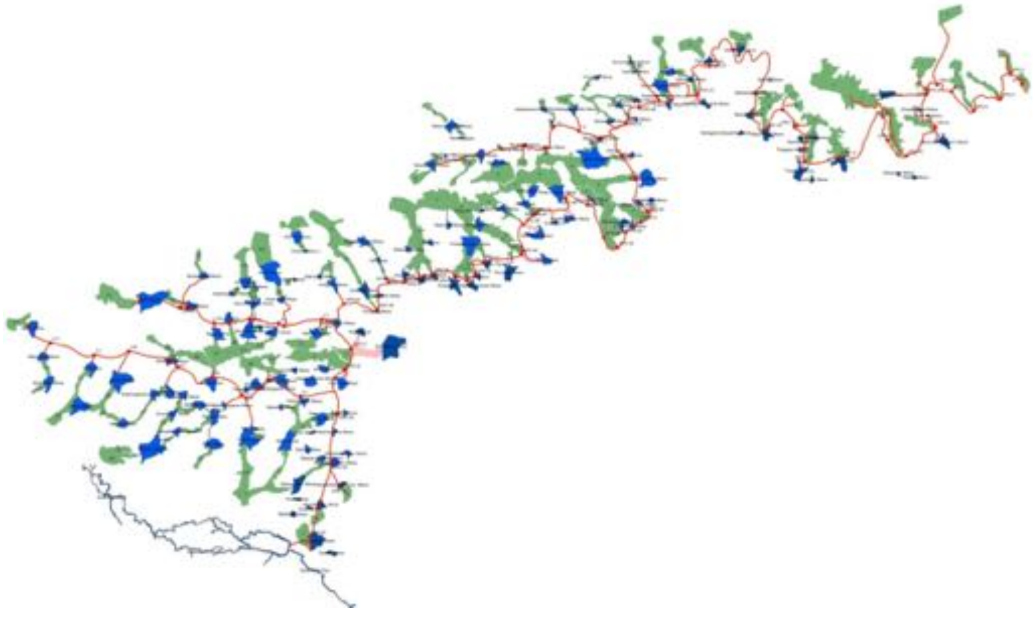


Figure 15 Ancient tanks and their irrigation areas along the Left Bank Canal network

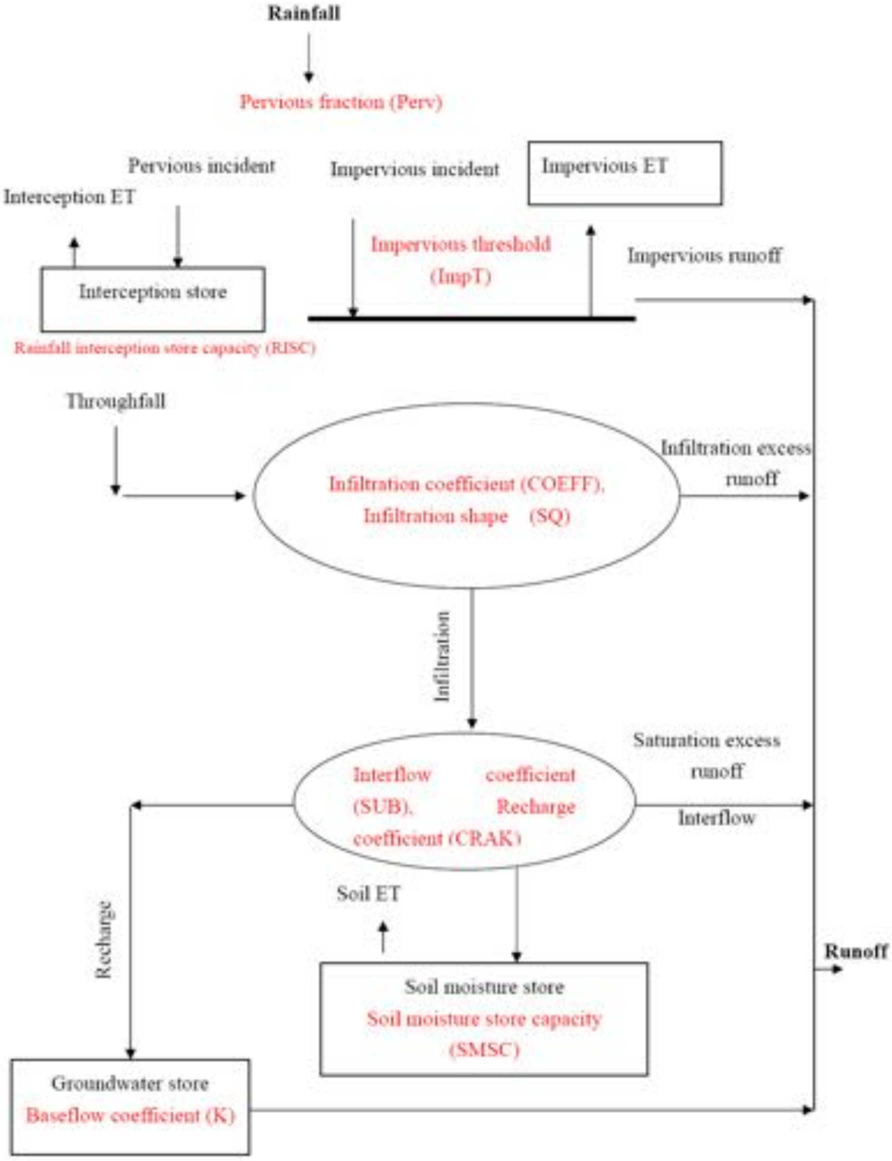


Figure 16 Structure of SimHyd rainfall-runoff model

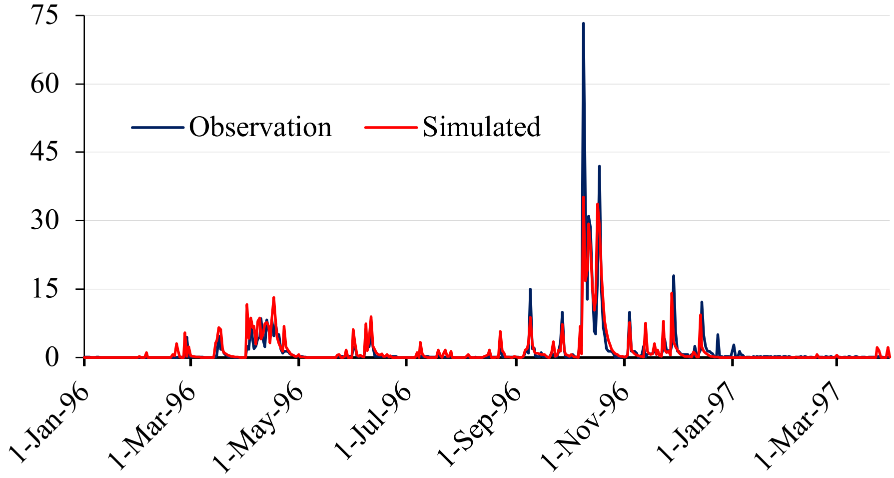


Figure 17 Comparison of observation and simulation daily runoff over validation periods

4.5 Inflow to Deduru Oya New Reservoir

The inflow to Deduru Oya reservoir is taken from the monthly inflow data from the feasibility study. The observed inflows shows a high variability amd the Normal year

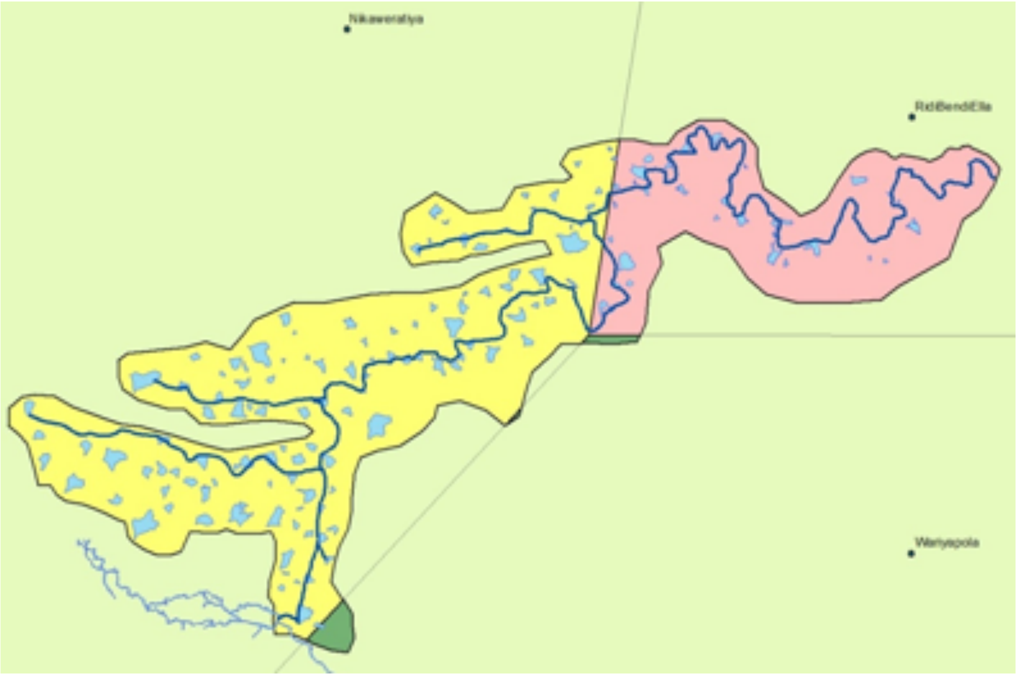


Figure 18 Thiessen polygons for estimating rainfall coverage area over the LB canal region

corresponds to the amount of flow with 50% probability. The inflow to ancient irrigation tanks connected to the LB canal is only about 2% of this normal inflow to Deduru Oya reservoir. Therefore the attraction of revived ancient tanks comes mainly from cultural, environmental and societal benefits and empowerment it brings at village level. In order to understand the role the ancient tanks can play, we considered the normal year flow conditions and extreme dry weahther codition flow. The dry condition is assumend to constitute of 20% (80% non-exceedance) monthly flows and these normal and dry estimates are shown in Figure 19.

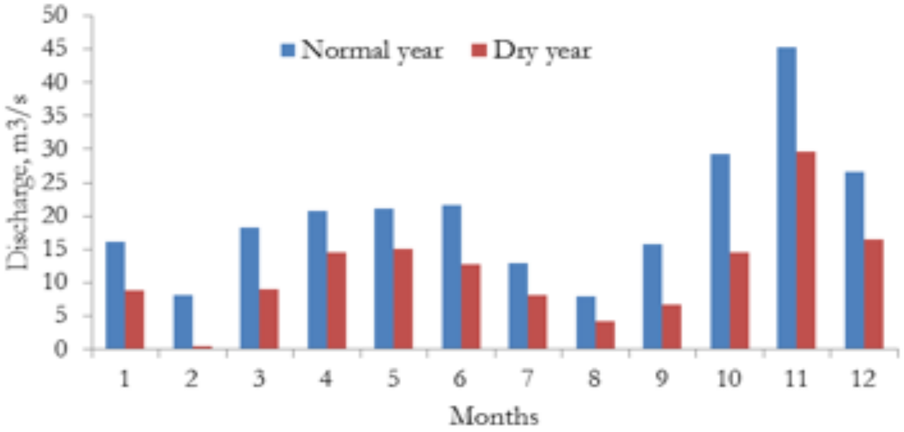


Figure 19 Deduru Oya inflows to reservoir during normal and extreme dry climatic year

Table 9: Comparison of surplus/deficit water in normal and extreme-dry climatic year

Month	Total water demand (m3/s)	River flow (m3/s)		Water surplus/deficit (m3/s)	
		Normal year	Dry year	Normal year	Dry year
January	8.62	16.1	8.9	7.48	0.28
February	8.3	8.2	0.4	-0.1	-7.9
March	21.83	18.2	9	-3.63	-12.83
April	11.22	20.7	14.5	9.48	3.28
May	19.33	21.1	15	1.77	-4.33
June	19.5	21.7	12.8	2.2	-6.7
July	10.08	13	8.2	2.92	-1.88
August	8.46	7.9	4.2	-0.56	-4.26
September	26.84	15.7	6.7	-11.14	-20.14
October	8.1	29.2	14.6	21.1	6.5
November	7.16	45.3	29.6	38.14	22.44
December	11.22	26.7	16.4	15.48	5.18

4.6 Water allocation

There are several tools, which are designed to help water supply and demand management in river basins. WEAP model was selected for this study because of its robustness and ease of use for developing and testing the water supply and demand management (Hussein and Weshah, 2009; Holf et al., 2007). The WEAP model is GIS based integrated water resources management tool that integrates different water supplies and demands at catchment scale. WEAP was developed by the Stockholm Environment Institute. The WEAP model uses the basic principle of water balance accounting. WEAP represents a particular water system, with its main supply and demand nodes and the links between them, both numerically and graphically. Users specify allocation rules by assigning priorities and supply preferences for each node; these preferences are changeable, both in space and time. WEAP then employs a priority-based optimization algorithm and the concept of equity groups to allocate water in times of shortage. The simplicity of representation means that different scenarios can be quickly set up and compared and it can be operated easily. Water allocation to demand sites is done through linear programming solution. Therefore demand site satisfaction is maximized subject to the mass balance, supply preferences, demand priority and other constraints. Figure 20 shows schematic view of study area at WEAP platform.

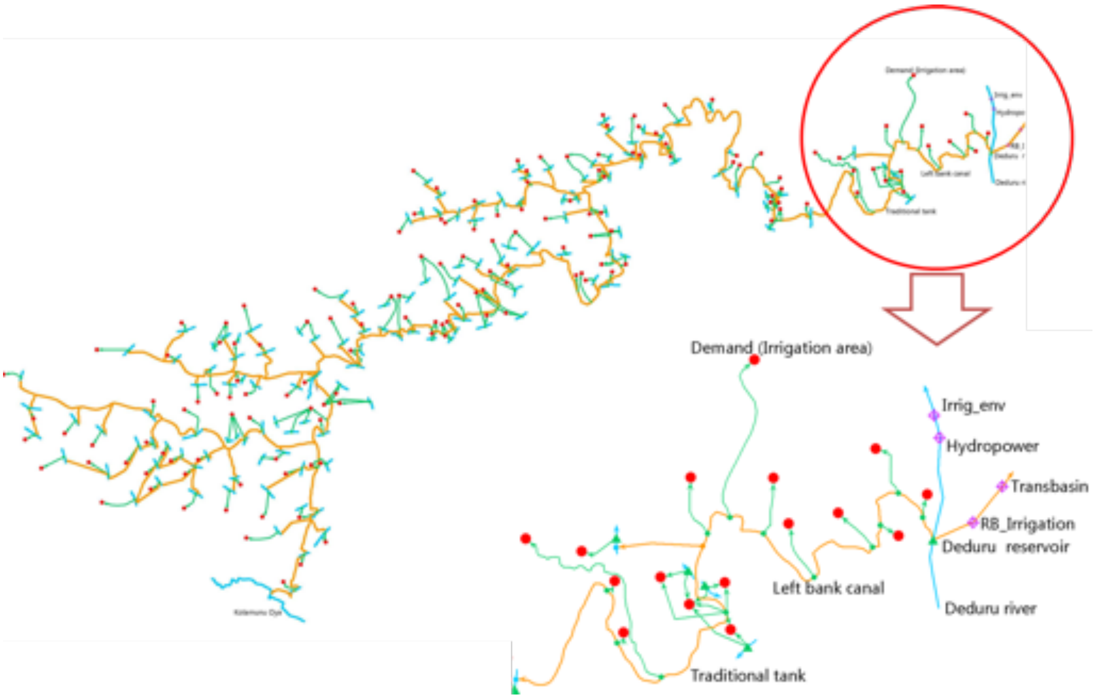


Figure 20 Schematic view of Deduru Oya Reservoir Project system at WEAP platform

Scenario analysis enables to answering of ‘what if’ questions such as: what unmet demands can be expected if current trends are projected into the future? What alternative allocations could be? How should reservoirs be operated? The following scenarios were created for developing and testing water supply demand management scenarios:

- Tanks only for two cultivation season for normal weather: The coverage and unmet water demands point out that most tank supplies alone are not able to meet the two season irrigation water requirements. Water shortages occur in the month of March, May, June and September.
- Tanks only with single Maha season cultivation normal weahter: Excluding few tanks, most of tanks are able to meet Maha season irrigation water requirements. Water shortage occurs for some of the tanks in September. However, tanks with full demand coverage are more than 75%.

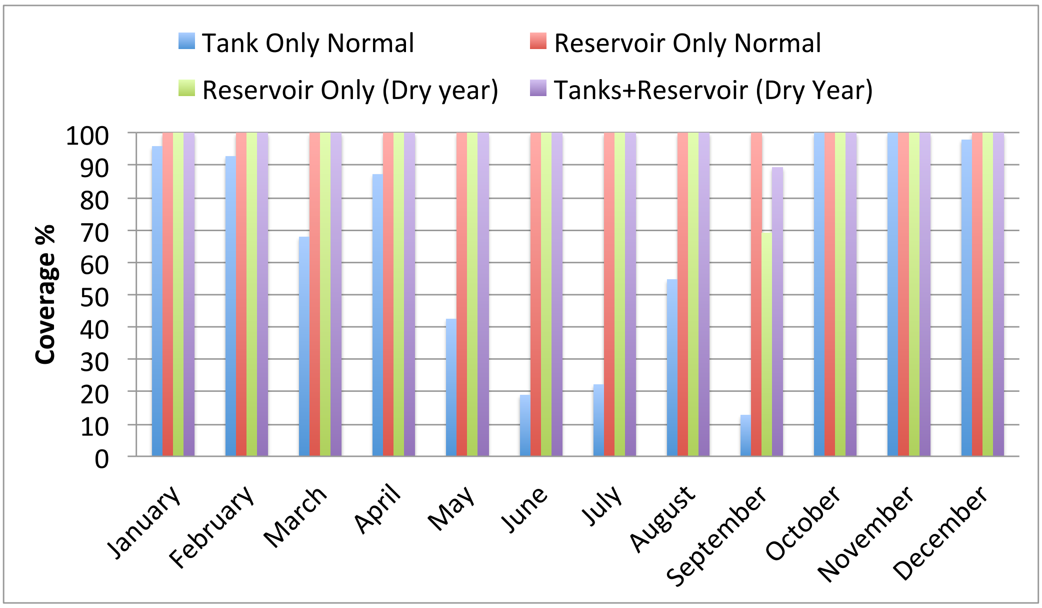


Figure 21 Coverage of irrigation demand under different source combination scenarios for normal and extreme dry weather conditions.

- Proposed Reservoir supply only for normal weather: Reservoir supply in normal climatic year is well enough to meet all the irrigation, hydropower and environmental flow requirements.
- Proposed Reservoir supply only for extreme dry weather at 20% monthly inflows: The total irrigation demand cannot be accommodated in the reservoir only scenario. Alternative water allocations need to be considered. Water shortage occurs in the month of September.
- Tanks and reservoir with extreme dry year flows: This modeling is carried out with operation of ancient tranks and the new main reservoir freely without any constrains. This arrangment improves the performance in meeting the irrigation demand, but still there is a shortfall in September where only 90% of the demand can be met.

The coverages of the above scenarions are summarized in figure 21. In order to achive full coverage during such extreme dry weather conditions it is necessary to understand the performance of individual ancient reservoirs. The scenario analysis shown in figure 21 is arrived assuiming ancient tanks are operated without constraints. The simulation shows that they also would fail in September. The performance of ancient tanks varies as they differ in storage volume and command area. The deficit volume in September in an extreme dry year is about 1MCM if only new reservoir is used for irrigation for the left bank. On the other hand the total capacity of the ancient irrigation tanks that will be connected to the LB canal is around 9 MCM. Even in the extreme dry run, the inflows to the ancient system is sufficient to meet the 1 MCM deficit from main reservior, if water is conserved for irrigation in Septemberin the ancient tanks. Thus, prioritizing September irrigation can help achieve 100% efficiency in an extreme dry year if the central water management by the irrigation department issuing LB canal irrigation water and the village tanks managed locally by the elected ‘Jalapalaka’ carries out water management jointly.

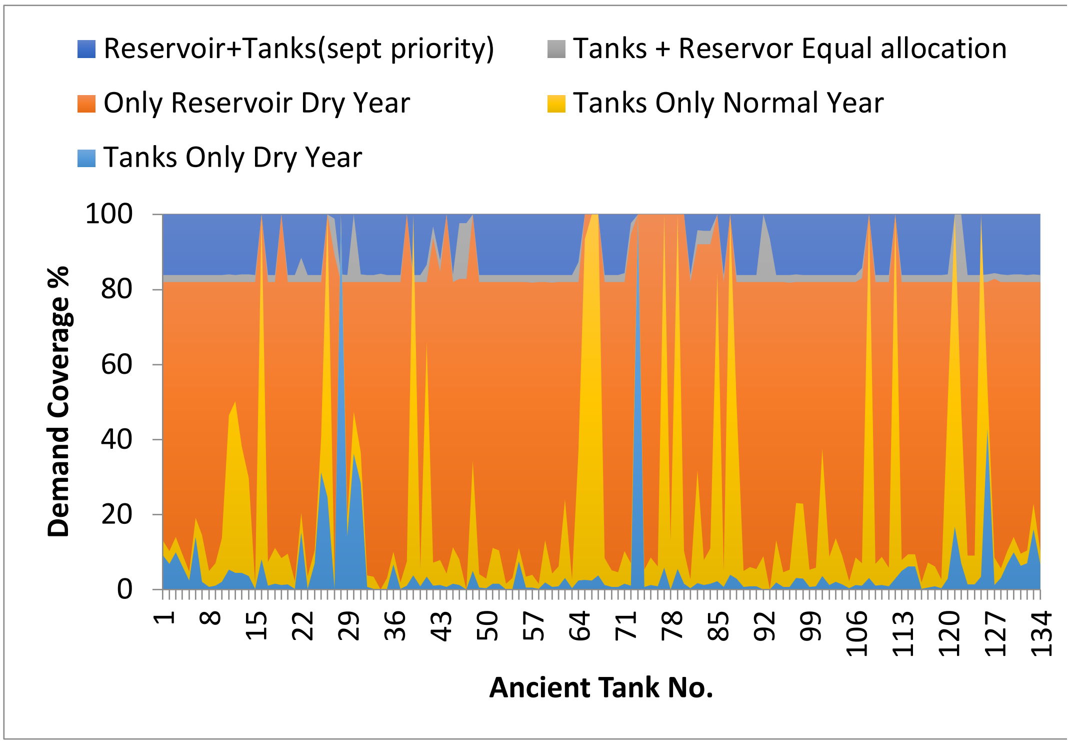


Figure 22 Irrigation demand coverage under different scenarios, including joint management prioritizing meeting September demand.

5. Water management in mosaic irrigation systems

Water management in the combined ancient and modern irrigation system require special attention as introduced earlier due to the different types of management strategies adopted in ancient tank irrigation and modern irrigation systems. In the ancient village tanks, the farmers are responsible for allocating a finite water accumulated during the rainy season among the farmers in the villages. In the modern systems irrigation department issues water at distribution canals and the farmers manage the water below this level through field canals. While the former operates in a system management concept, the later in general obtain water when and needed from the free flowing canals. However, in recent times experimental water management in modern irrigation systems based on allocating finite water volume from the flowing canals, termed Bulk Water Allocation (BWA) has proved to be effective and efficient. In this study, adaptation of BWA in the Deduru Oya Mosaic system is investigated.

6. Water Management in Ancient Tanks

Traditionally water management in village tanks were carried by a manager called 'Vel Vidane' who is paid with a share of rice grown by villagers (Samarasinghe and Sumanasekera, 2005). This renders *Vel-vidane* accountable to all the villagers as he allocate water according to the water availability in the tanks. A unique feature of this management is a practice called 'Bethma' where land near water source is re-allocated temporarily to enable everybody to cultivate during season of scarcity. Farmers may grow either paddy or other crops on the land allocated. Land may be allocated proportionately to original ownership, but in general non-proportional with each land holder getting one plot as allocated by Vel Vidane. Some pressure by vel vidane is needed as small holders would not benefit if proportionately distributed, and large holders feel unfairness if equally distributed. After the British abolished the Vel Vidane system, the water allocation is now carried out by Farmer Association (FOs) or by an appointed 'Jalapalaka'. Figure 25 shows the general distribution of the paddy fields where the old (core) area identify the area that can be cultivated during water scarcity periods and is redistributed under Bethma system.

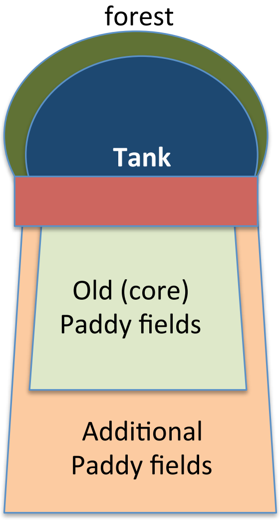


Figure 23 The distribution of paddy fields under tank

In recent times Bethma practice is on the decline in many areas. New agro-wells and other ground water sources also have contributed to expansion of additional paddy fields, which makes it difficult to judge eligibility of land under Bethma. Many work around to avoid Bethma – starting second season early before a decision is taken. The reason for avoiding Bethma is due to the investments farmers have made on their fields in terms of fertilizer and weed control. In some areas those who could not cultivate in ‘Maha’ season is given priority in ‘Yala’ season. In the Deduru Oya basin it was found that many farmers are reluctant to share land under re-allocation scheme during the dry periods.

7. Modern water management practices

Modern1 Participatory Irrigation Management in Sri Lanka started back in the 1980s. Before 1980, major irrigation scheme, Gal Oya, was reported to be uncooperative and experienced constant violence. The upstream was dominated by Singhalese and the downstream by Tamil. The participatory management work was anticipated to be very difficult. However, participatory management was built up successfully throughout 1980-1985 with the help of Irrigation Organizer (IO), external catalysts who play crucial roles in gaining farmers' trust and bridging government agency and farmers (Uphoff and Wijayaratna, 2000). Farmer organization in Gal Oya has been repetitively reported as a success story, exemplified almost a decade after implementation during the 1997 dry season, where a much larger plot of land were successfully cultivated in the area due to efficient farmers' organization despite severe water scarcity (Uphoff and Wijayaratna, 2000).

Subsequent failure by the government to collect irrigation fees to recover the operation and maintenance cost of irrigation systems in the country, and success in Gal Oya prompted 'Participatory Management Policy' 1988 to hand over operation and maintenance work to farmers themselves. Following this policy, INMAS (Integrated Management of Major Irrigation System), MANIS (The Management of Irrigation System) and Mahaweli Authority have implemented participatory approach in 35 major schemes, 160 smaller major schemes and 4 major schemes in the Mahaweli Basin respectively (Brewer, 2004).

In the year 1990, Irrigation Management Policy Support Activity (IMPSA) was established in the country to assess recent experience of participatory management, and recommend suitable policies and guidelines. Through consultation of farmers and officials in Colombo, a consensus was to be achieved on what to do for the next decade (Merry *et.al*, 1991). IMPSA secretariat went through numerous good effort, and produced a series of ten very helpful Policy Papers, guiding the steps to establish Farmer's Organization, build capacity and strengthen the institution in Sri Lankan context.

8. Bulk Water Allocation System (BWA)

The concept of ‘Bulk Water Allocation’ (BWA) was introduced into the area for pilot testing to find out a methodology, to be used as a broad-based solution for water management problems in major irrigation schemes (Gunaratne, 2003).

The system starts from the smallest unit of Field Canal Group, with an elected field canal leader. All field canals under one distributary canal belong to a DCFO, led by an elected leader. Leaders of 10-12 DCFOs would come together and attend monthly Unit Level Committee Meetings, chaired by Unit Manager with Technical Officers as secretary. Unresolved problems from these meeting would then be brought to monthly Block Level Committee Meeting, which is attended by all 38 DCFOs in the block, Block Level Officers (including a block engineer, officers for community development, agriculture and institutional development) and *Jalapalaka,* the elected water manager. Unresolved problems from this meeting would then be brought to Project Level Committee Meeting held once in every two months, chaired by Resident Project Manager and attended by farmer representatives. With the institutional environment, problems and conflicts resolution, decision-making and information can flow transparently and systematically from lower level to upper level, and *vice versa*, supporting the proper functioning of the whole system. The structure of the water management system is shown in Figure 24.

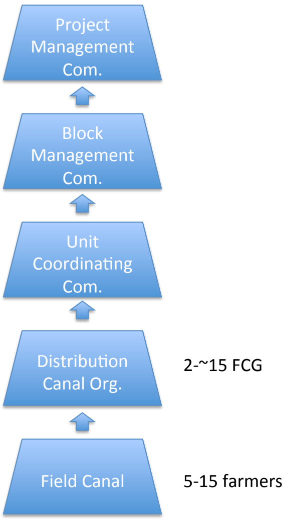


Figure 24 Management structure of system H in implementing BWA

In a pre-cultivation-season meeting, farming community get together to discuss and decide on their own cultivation plan, water issuing dates etc. In a jointly managed system like the Mahaweli H, as farmers rely on the higher level for water allocation, a pre-season meeting offers an extra step for farmers to propose what they wish to cultivate themselves, taking into consideration climatic, soil conditions and market demand. Water demand calculation begins from the individual farmers in a field canal. The cropping pattern and required water is then aggregated at the field canal, then distributary canal and handed on to block level. The summing of requirements from all blocks constitutes the system requirement. Local officers would usually negotiate and discuss with farmer leaders to come up with a reasonable plan. The Resident Project Manager would then send this requirement to the Water Management Secretariat (WMS)[1] to request for diversion of water to system H for

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[1] The management of the water resources of the Mahaweli Project is entrusted to the Water Management Panel (WMP) which is headed by the Director General of MASL and consists of all Heads of Government Agencies concerned with the management and operation of the Mahaweli Project. The Director of Water Management Secretariat (WMS) functions as the Secretary of both the Policy Planning Panel and the Mahaweli Water Management Panel, and this helps to maintain the necessary communication link between the two panels. The WMP is also responsible for the overall cultivation programmes in the areas served by the Mahaweli Project. The WMP is assisted in its works by a

the season (Gunawardena and Wickramaratne, 2011). If the amount of water requested is available, the demanded bulk water would be granted. If not, cultivation plan would be adjusted and finalized in Cultivation-Season-Meeting, together with water issue dates and other details. The system attempts to simulate a water storing tank, where a fixed amount of water is available for farmers in the beginning of a season. Like a bank account, any withdrawal or deposit would directly affect future availability of water. Engineers are responsible of updating the balance. Farmers learn to manage water with these virtual figures as guidance.

Jalapalaka or water master plays a crucial role in the operation of water distribution. Their duties include issuing water according to timetable, keep recording of water account from reading of calibration chart and gauges, collecting rainfall data, reporting on crop progress and arising issues. There are two types of *jalapalaka*, those in charge of distributary canals, selected and paid by their respective DCFOs, and those in charge of main canals and branch canal, selected in Block Level Committee Meeting but paid by the government. A high level of cooperation and coordination between these 2 types of *jalapalaka* is required to ensure smooth water issuing, as water can also be released into distributary canals on time if it is released in the main canal or branch canals on time in the first place. They usually undergo intensive training, mostly by the irrigation engineer. DCFOs rely heavily on their *jalapalaka* for water distribution and coordination with block level officers.

Performance of water supply after introduction of BWA has increased considerably in terms of gross water quota allocated at the block levels and the main canal level for both seasons. The extent cultivated during dry season has increased 52%, with an increase of annual cropping intensity by 10.7%. In the past, farmers adopted '*bethma*' system in water scarce seasons, which ceased after the implementation of the BWA system. After the initiation of BWA, 45% of farmers have changed their cropping pattern by introducing new low water consumptive and high value cash crops. The majority of such farmers are in the tail end areas, accounting for 60% of total farmers. Crop diversification has been one of the main activities undertaken by the MASL (Aheeyar *et.al.*, 2007).

BWA, which emulates a tank is the ideal system to be adopted in the new Deduru Oya project where water management has to be closely coordinated between the modern reservoir and the ancient tanks.

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technically specialized Water Management Secretariat (WMS) constituted within the MASL. It is responsible for the operational planning and coordination responsibilities of the WMS extend to the other operating agencies as well. The WMS provides information and recommendations to the WMP to assist it in reaching its operational policy decisions. Once the decisions are made, the monitoring of the total programme is directed by the WMS.

9. Implementing BWA in Deduru Oya basin

With the completion of Deduru Oya Reservoir Project, there is a necessity to implement a new water management system, as the irrigation from canals is completely different from tank irrigation. In order to understand the requirements of new farmer organizations (FO) after the completion of the Deduru Oya basin an extended field study was carried out organizing discussions with four FOs in four villages, interviewing 16 farmers and holding discussions with Field Level Officers who are Agriculture Research and Production Assistants overseeing the minor irrigation schemes. Major issues identified are summarized below that can be taken into consideration when new management structures are implemented.

Unlike from a tank, it is impossible to visualize the total amount of water that would flow through the canal to the field. It is thus difficult to divide water equally. Water source is relatively unsecure compared to tank water and water issues dates are inflexible. Farmers need to learn to irrigate in a limited time period. Overall, a more sophisticated management system than the current one is required. The jalapalaka committee and their decision-making cater to the physical structures of the village, while addressing equity and efficiency simultaneously. To improve water use efficiency, a quantitative understanding of water use needs to be instilled among farmers. Measuring device should be provided in tank and turnout to measure the water use each time. Farmers should acquire the knowledge to calculate and understand whether they are conserving or wasting water. Further training can be provided on best practices to conserve water and prevent wastage.

Rehabilitation of irrigation structures e.g. gates for turnouts are also to be carried out as soon as possible with external financial and technical assistance to enable proper water management to take place. There is a lack of financial capacity, technical and management knowledge regarding irrigation system. Intensive training about maintenance of canals and water management should be provided to all farmers if possible. Awareness programmes must be held simultaneously. Awareness programmes also strive to correct the attitude of farmers, regarding attending meetings, voicing up of opinions, and compliance and enforcement of rules.

At present, when water level in the tank is low, water would not be withdrawn for cultivation but reserved for animals and domestic usage. Farmer leader is well aware about issues of environment and sustainability. These awareness and values are valuable and should be best possible maintained in the future while production-orientated mindset is best to be avoided. However, it is also recognized the need of awareness programme to correct some of the farmers’ attitude, especially rule-breakers.

10. Conclusions

The new Deduru Oya reservoir will provide water resources many folds over the current existing ancient irrigation tanks in the Left Bank canal side of the Deduru Oya area. The main focus therefore would be to provide the social and cultural cohesion, harmony with nature and resilience in extreme events utilizing the ancient irrigation network. The enhanced water resources provide opportunities to improve livelihoods of the farmers in the region. Thus, a holistic approach towards empowering the farmer communities through integrated water management practices is necessary to make full use of the Deduru Oya irrigation project.

The analyses of inflows to both new and ancient irrigation systems shows that the reservoir alone will have around 15-20 times the water resources available compared to the ancient systems, and is capable of supporting year-round irrigation and additional coverage for rice farming. However, the ancient irrigation systems can play a major role in providing the resilience to the system to absorb shocks from an extreme dry climatic year. With the enhanced inflows from the modern reservoir they will be able to provide water for year round cultivation of existing farmlands and also provide opportunities for grow other food crops to enhance income.

The challenge facing the system is the design of an appropriate water allocation system and implementing a robust water management system. The WEAP model employed showed feasible water allocation scenarios and can be used to construct appropriate operation rule curves for the reservoir, combining with the demands of right hand canal, which was taken into to analysis but not discussed in detail here. In addition, the various inlet structures, such as level crossings and cascade supplement can be individually accounted for in the detailed water allocation model constructed for the combined new and ancient irrigation systems.

For water management, the Bulk Water Allocation (BWA) model adopted in system H of the Mahaweli basin was studied and found to be a promising model to be used in the Deduru Oya basin project. The assessment of implementing BWA through a detailed survey of the Deduru Oya basin has been carried out and showed a positive attitude by the farmer community. In implementing the BWA, it is important to establish (a) clear and measurable water entitlement, (b) incorporate ‘risk management’ in comprehensive capacity building that includes social, technical and financial aspects and provide (c) transparency in decision-making and appropriate power sharing.

The Deduru Oya project provides a unique opportunity to combine the efficient large-scale modern systems with resilient localized ancient systems promoting social and harmony with nature though building mosaic systems. These mosaics should cover both physical (structural mosaics) and social (management mosaics) aspects. Further analysis on economic aspects, in linking micro production with macro economy through crop and livelihood diversification should be studied in future.

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