IMPORTANCE OF EVAPORATIVE DEPLETION BY NON-CROP VEGETATION IN IRRIGATED AREAS OF THE HUMID TROPICS

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ABSTRACT

In tropical, monsoon climates of South-East Asia, irrigation facilities supplement rain in the wet season and allow for crops to be cultivated during the dry season. In these areas, water needs are typically estimated by considering the evapotranspiration of imgated crops, plus water requirements for seepage, percolation and drainage, particularly in rice irrigated areas. But, these considerations are insufficient in design, management, and characterization of performance in many areas. Recycling, or reuse of return flows, plays an important role in most rice-irrigated areas in the humid tropics. Additionally, depletion of water by non-crop vegetation can represent a significant component of the water balance.

In the Dry Zone of Sri Lanka, an average annual rainfall of 1000 mm falls mostly (70%) in a 3 month period. During the dry season, reference evapotranspiration less rainfall is about 700 mm, indicating that much additional supply is meant to support crops. In this climatic context, irrigation has dramatically changed the local environment by allowing eco-systems quite similar to that of the wet zone to flourish. In these systems, recharge of shallow groundwater by percolation from imgated fields, canals, and tanks, has provided a continuous supply of water for natural vegetation and homestead gardens. Much of the water used by this non-crop vegetation is beneficial. Growth of fruit and coconut trees can be quite profitable, while other trees enhance the environment. A first estimate of the water balance made in 1996 in part of the command area of the Kirindi Oya irrigation scheme, Sri Lanka, shows that evapotranspiration by non-crop vegetation to be similar to that of the rice, the main crop in the area.

In 1998 IWMI performed a comprehensive water balance in the area, based on surface flow measurements, rainfall data, and estimation of crop water requirements. This water balance showed that evaporation consumed 78 % of the

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total amount of water available (net inflow minus committed). The amount of evaporation is split into process depletion - crop for 28 %-, direct evaporation from tanks (7%), inter-seasonal fallow (10%) and from non-crop vegetation for 55%. A further analysis using remote sensing techniques has fully confirmed that perennial vegetation covers most of the non–paddy areas, and consumes a large amount of water through withdrawal from the groundwater.

The main conclusion from this study is that non-crop vegetation is a significant consideration in tropical humid environments in planning, management and performance assessment. Designers, managers, and researchers need to specifically incorporate the evaluation of evaporation by non-crop vegetation in their approach of water requirements. Further investigation is needed to estimate water consumption per sub-class of non-crop vegetation and to assess their respective beneficial use.

INTRODUCTION

In monsoon areas of South-East Asia, irrigation facilities supplement water supplies for rice during the monsoon, and store additional water to be used on crops during dry seasons. Irrigation water delivery requirements are typically calculated by considering the net evapotranspiration requirements of rice (potential evapotranspiration less effective precipitation) plus amounts required for seepage and percolation for rice. Performance is often evaluated against delivery of these requirements. This is divided by values of conveyance times application efficiency. But, it is now well recognized however that aggregation of irrigation requirements in this manner does not lead to a comprehensive and consistent picture of water requirements. This is true because recycling of water is very common in rice areas, and is required in the tank cascade systems common in Sri Lanka (Sakthivadivel et al, 1996).

Furthermore, water needs within an irrigation scheme are not limited to crops, but it is also nowadays recognized that irrigation has some good and/or bad effects on the other water uses such as domestic, environmental and industrial uses of water. Irrigation in these regions may provide benefits far beyond allowing for crop production.

In the dry zone of Sri Lanka, irrigation in old schemes has led to dramatic changes of the environment by allowing for perennial vegetation and homestead forestry gardens which are usually only found in the wet zone. Growing of trees, mostly coconut, is made possible by high groundwater levels induced by imgation. Water from rain and groundwater sources allows trees to survive dry periods (the Yala season from April to October). Other trees grow naturally under these favorable moisture conditions.

It is not surprising that water used for perennial vegetation can reach a large proportion of the total amount of water made available in a given irrigated area. More surprising is that little consideration has been given to water consumption by trees and other non-crop vegetation within irrigated areas. This is perhaps due to a few reasons. Much of our efforts have been focused on the delivery water as a performance measure, not necessarily on how water that is not consumed by crops is used. Recently, because of a focus on water scarcity, more focus is placed on the overall water balance of irrigated areas, thus other types of consumption besides crop consumptive use becomes more important.

This study focuses on the Kirindi Oya Settlement Project situated in South East Sri Lanka. A preliminary water balance survey was made in the old irrigated part in 1996 that indicated that half of the total consumption during the dry season was through evaporation by perennial vegetation covering about the same area as paddy (Mallet, 1996). In this kind of environment where consumption of water resources by non-crop vegetation is a very significant part of the balance, it is impossible to efficiently manage water on the solely basis of crop areas, which is the current practice. An accurate assessment of non-crop vegetation consumption is a sine qua non condition to improve the performance of the scheme. To more carefully address this issue, IIMI carried out a one year study in 1998 on the entire area of the project with the goal to measure or estimate the main outputs of the water balance including consumptive use by non-crop vegetation. The main results of the study are shown below.

BACKGROUND ON PERENNIAL VEGETATION

Perennial vegetation, whether planted on homesteads, or growing naturally in irrigated areas, has contributed a lot to improve the environment as a whole (A. Wickramasinghe, 1992). There are many benefits to the presence of perennial vegetation:

- It provides shade and coolness, and allows escape from the harsh tropical sun.
- It allows for increased bio-diversity within the ecosystem.
- Homestead forestry garden is an important source of income for farmers.

In Sri Lanka, irrigation developments have been made with the goal to provide net settlers with irrigated paddyfield of 1 ha and a homestead plot of land of approximately 0.2 ha. Established farmers in the area may possess greater areas in paddy and homestead. As in other regions such Kerala in India, (A. Salam and D. Sreekumar, 1991) homestead gardens in Sri Lanka are of great importance for farmers to provide them with food, medicinal plants, fuelwood, a pleasant environment, and raw materials for handcrafts. One of the favorite trees planted by fanners in their forestry garden is Coconut palm tree which is called "the tree of life" because every part of it is used (G.J Persley, 1992): meat, leaves, cocoshell, husk, trunk, cocowater, and roots. In addition to homestead garden, natural vegetation along rivers, ditches, canals, represents another source of water depletion which has to be accounted for in water balances.

Impact of perennial vegetation on the water balance

Perennial vegetation has two major effects on the water balance:

- reduction of the contribution of rainfall;
- increase in evaporative depletion of water resources within the irrigated area

It is well known now that perennial vegetation reduces the rainfall contribution to run-off because of interception. Part of the rainfall is intercepted by the canopy, evaporates directly without reaching the ground. Values of interception coefficient (percentage of rain that is evaporated by the process of interception) can be found in literature, although some discrepancies can be found between authors. Basically the interception coefficient varies with the density of vegetation and with the regime of rainfall. Interception in tropical areas is usually less than in temperate climates. For the latter, frequent and low intense rains can lead to values as high as 40 % as reported by Calder (1993; 1998). For tropical forests, reported values are 13 % for Amazonia to 21% in Indonesia (Calder, 1993), 17% in lowland rainforest of Malaysia to 20 % in the Philipinnes (Bruijnzeel L.A.S., 1997). Balek (1977) cited in Radersma and de Ridder (1996), estimated that 70-80% of precipitation reaches the soil below rainforests (20 to 30 % of interception).

Tropical perennial vegetation transpires on a continuous basis throughout the year. Because roots can tap groundwater, transpiration are at full level during much of the year. Therefore it was hypothesized that consumption of water from perennial vegetation in irrigated areas might be high in terms of volume per unit area.
The source of water for perennial vegetation is from rainwater and indirectly or directly from irrigation supplies. Irrigation supplies and rainwater percolating past the root zone enters a shallow groundwater system where it can be tapped by

tree roots. Part of this water would have re-entered the drainage system and been available for crop evapotranspiration, or would flow out to the Indian Ocean.

THE STUDY SITE

The Kirindi Oya settlement project completed in 1986, is located in the dry zone of Sri Lanka. Average annual rainfall is 1000 mm with a dry season (Yala season) from April to October. Minimum average temperatures vary from 26 °C in December to 28 "C in April. The project, see Fig.1, consisted mainly in the construction of a new important reservoir (Lunugamwehera) meant to:

- secure supply **to** the existing old system, "Ellegala", of approximately 5000 ha (EIS);
- develop news areas on the left and right banks of the Kirindi Oya river, upstream the old system, for another 5 000 ha (NIS) to serve the needs of new settlers.

Settlers in the new areas receive treated water from the Luhunugamwera Reservoir, while farmers in the old areas rely on private wells for domestic needs.

The project is located on the downstream part of the Kirindi Oya Basin, before the river reaches the Indian ocean. Several peculiar features are important for the understanding of water management:

- it is a tank cascade system where drainage water is captured in downstream tanks and recycled again for irrigation. It is estimated that ***66%*** of the NIS command area is recycled in the EIS;
- Excess drainage water flows into the Indian Ocean in excess of downstream of environmental needs, and the basin is considered open (Seckler, 1996).
- part of the old Ellegala system, is considered as a wetland sanctuary site of international importance (Wetland Conversation Project, 1994).
- the Bundala National Park is a coastal area made of several brackish water lagoons where ocean water is mixed with fresh drainage water from irrigated areas. It is believed that salinity levels are dropping below the natural level because of excess irrigation drainage flows, thus endangering the natural ecosystem.

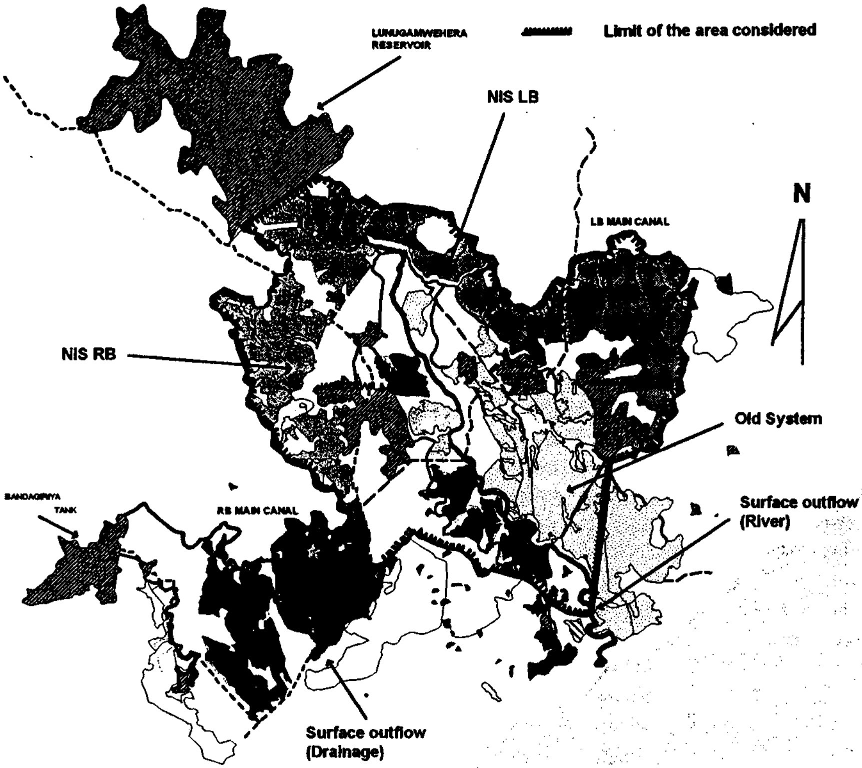

Fig. 1. **Map** of Kirindi Oya Settlement project.

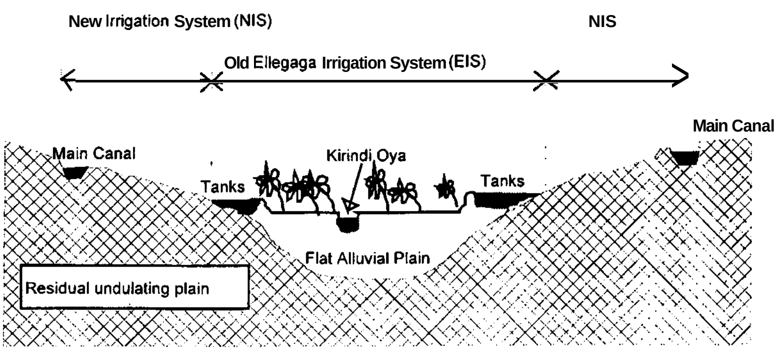

Fig. **2.** Schematic cross section of KOIS Project.

PROBLEM DESCRIPTION

Since its implementation, the project has supplied the whole area during the wet season, but it has not been able to provide enough water to sustain a second crop during the dry season for the entire project service area. *An* over estimation of water availability is often advanced as the reason for the gap between designed and actual irrigated areas. However it is clear that water requirements have been based only on estimations of requirements for paddy (rice) without taking into account additional evapotranspiration from perennial vegetation. This can be a major cause of discrepancy between predicted and actual consumption.

Kirindi Oya is not an isolated example for this type of problem. All the major irrigation schemes in Sri Lanka (400 000 has) in the dry part of the country are significantly covered with non-crop vegetation (mostly perennial). This situation is very common in many areas of the humid tropics.

Perennial vegetation at Kirindi Ova

In Kirindi Oya scheme, perennial vegetation has largely developed over time and now covers a great **part of** the area (Fig. 2). It must be underlined that the importance of perennial vegetation is the result of paddy cultivation. Other crops and other irrigated techniques at the field level would have led to a complete different picture. **A** survey made during Yala 98 has shown that on average groundwater depth in the old system (Ellegala) varies from 1.6 meter to **2.8** meters. Tree roots can readily tap groundwater of this depth even in the dry season.

Vegetative coverage in the Old System **(EIS)** is much more than the New System (NIS) **for** three main reasons:

- historical – the old system has been in existence from ancient times, while the new system development is recent (14 years);
- topographical – the light soils **of** the undulating NIS command area are quickly drained once irrigation is cut **off;**
- managerial – so far the intensity of irrigation in NIS has been low, reaching only 103% per year (Renault, 1997), i.e. one crop per year, which does not allow to **sustain** wet zone type perennial crops throughout the all year.

A preliminary water balance was made in 1996 on part of the EIS (2000ha) during a period of **45** days (Mallet, 1996). Recorded values are displayed in Table 1, it was estimated that perennial vegetation evaporates a similar amount of water than paddy fields.

INPUTS		OUTPUTS		
Irrigation issues	Rainfall	Crop evapotranspiration	Drainage	Others Perennial vegetation
11.5	0.6	3.8	4.8	3.5
95%	5%	32 %	39 %	29 %

The importance of perennial vegetation in the area has been also analyzed by looking at aerial photographs. Even in urban areas (called settlement areas and/or homestead gardens), the density of perennial vegetation is important. In homestead gardens, the vegetation is generally developed in three layers. The highest is composed of coconut trees, the medium of fruit and medicinal trees and the lowest of vegetables and grass. It can be concluded that the whole area is an evaporative surface made of paddyfields and fallow, water bodies and perennial vegetation.

It must be pointed out that perennial vegetation is found in non irrigated areas of the dry zone. It is however mainly composed of shrubs and small and drought adapted trees which evaporate much less than their well fed counterparts of irrigated areas.

WATER BALANCE

During the 1998 calendar year, measurements have been carried out to establish a water balance within the scheme. The water accounting figures are reported in Table 2., following the framework proposed by Molden (1997). Details about measurements and evaluation are given below.

The studied Gross Command Area

The water balance domain is shown in Fig. 1. The domain does not completely coincide with the entire command area because of the points selected for reliable measurement. Part of the downstream left bank in the old area EIS and parts of the right bank main canal in NIS are not incorporated in the water balance. Drainage **from** these areas was not measured. The water balance domain is bounded by the main canals in the north and the limits of the outflows catchment areas in south, the impermeable layer of the underlying aquifer. and is taken for a one year time period (January lrst to December 31rst 1998). The water balance domain area covers a Gross Command Area (GCA) of 25,638 hectares as measured by remote sensing image.

Uncertainty in water balance computations come from two sources. We are not certain that the downstream boundary coincides with the catchment area that drains to the measuring point. Second, there are small external watersheds which drain to the main canals which we have assumed to be negligible. Other uncertainties come with measurement errors and estimates of evaporation and evapotranspiration as described below.

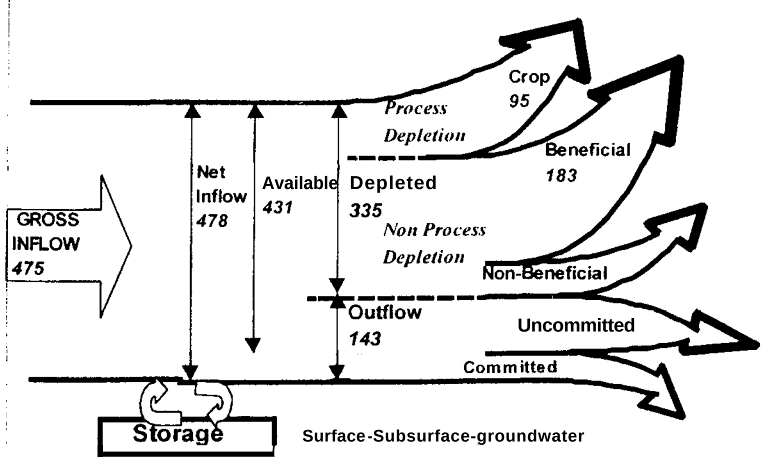

Fig. 3. Water Balance in Kirindi Oya *(Figures are in mcm, million cubic meters)*

Table 2. Water balance in Kirindi Oya Project for *1998.*

INFLOW		NET Inflow[1]	Committed	A	Uncommitted	Process depletion CROP	Non-Process depletion	
Irrigation	Rain						Beneficial	Non Beneficial
245	230	478	47			95	184	56
		100%	10%	90%	20%	20%	38%	12%
475							240	50%

Gross Inflow

Rainfall: Rainfall is measured at three locations within the scheme. The average rainfall on the domain for **1998** was **897** mm, which is **10%** less than the long term average. The input from rainfall has been estimated for the GCA to **230** mcm, which might be considered as a minimum given the presence of external small watersheds (not accounted for).

Irrigation: Issues from the Lunugamwehera reservoir located across the river upstream **of** the scheme (Fig. 1) are measured twice a day. Issues accounted for in the water balance are those recorded on both **left** and right bank headworks. A total of **246** mcm has been issued during **1998.** Thanks to heavy rains late **1997,** water resources were abundant in **I998** and the irrigation intensity reach the maximum **(200%).** The irrigated area of the studied GCA amounts to **8619** ha.

Net Inflow

The net inflow is the Gross inflow minus the storage variation. In the domain under consideration there are three types of storage, surface, subsurface and groundwater. The surface storage is made of four major tanks in the old system totaling a capacity of **27.4** mcm. The storage volume has decreased between the lrst of January and the 31rst of December of an estimated volume of **2.7** mcm. The subsurface storage is the water stored within the soil matrix under irrigation. Given the fact that the area under irrigation has not changed, it is assumed–that there is no subsurface storage variation between the start and the end of the year study. The storage groundwater lies for the main part in the flat alluvial plain of the old area, Fig. **2.** It is also assumed that there is no significant groundwater storage variation. December is in the middle of Maha season (wet), and groundwater is always at the highest level due to the conjunction of inputs from both rain and irrigation.

The devleted flows

Process Devletion: Water that is depleted by intended uses is considered process depletion (Molden, 1997). Water is delivered to primarily to irrigation use. Other process depletion is through the piped water system delivering water to farmers, but the amount of this entering the water balance domain is considered neglectible. At times water is intentionally released in the canal for bathing, but it is assumed that this is not depleted, rather enters the groundwater system and is available for use (van **Eijk,** 1998).

Crop evapotranspiration has been estimated for the period of reference, using Pan Evaporation data recorded at Lunugamwehera reservoir with **usual** conversion factors and crop coefficients. For the 8619 ha irrigated within the GCA of the studied area, the crop consumption for two crops per year has been evaluated to be 95 mcm. For the 1998 Yala season (dry), the evaporation has been estimated ***to*** **720** mm. Monthly values for Maha season **(128** mm) are much lower than for Yala (180 mm).

Non process devletion: Non-process uses are natural and other unintended uses of the water resource. Non process depletion is mainly evaporative depletion by non-crop vegetation, inter-season fallow and free surface (water bodies).

Out of the **25** 638 hectares of the gross command area, only 8619 ha are irrigated. The remaining part (17019 ha) includes different types of land uses: such as water bodies (tanks), urban areas, homestead garden, forests, canals, roads, etc. Except for water bodies, this study represents the most comprehensive approach to estimating the non-process depletion. However, aerial photographs study has shown that non paddy areas are covered to a large extent with vegetation. Therefore, it is no surprise that water consumption for this land use and for non process depletion is very high.

The water consumed by perennial vegetation has been classified into one single category: non process beneficial. However there is a need to distinguish subclasses within the vegetation, from high dense perennial vegetation (beneficial) to shrubs (low beneficial).

Evaporation from fallow land and free water surfaces is categorized as non-beneficial. The amount of water evaporated from fallow lands is computed from the Pan evaporation records with a crop coefficient of **0.5.** This fairly high coefficient is supported by information derived from an on-going remote sensing analysis. The total amount estimated then for the fallow period is 32 mcm, which represents an average 74 mm per month. The evaporation from water bodies (tank) has been estimated using the entire area covered by the tank at full supply level, and the pan evaporation measured at the main reservoir. The estimated amount of evaporation for the whole year is 24 mcm. Given the shallowdepth in the tanks, usual in Sri Lanka, it is assumed that evaporation do not decrease significantly with water level as lateral water transfers through the tank bed feed areas no longer under water.

The water consumed by non-crop vegetation in the GCA has not been directly assessed, but is calculated firstly as the closure term of the water balance. As such it incorporates of course all the uncertainty attached to other terms. In a second step the perennial vegetation consumption has been estimated from a RS image during Yala 1996. No major deviation has been stated between the two approaches, as discussed below. From the closure of the water balance it is estimated that 184 mcrn of water are consumed through non-crop vegetation. It represents an average 1200 mm/year.

The committed and uncommitted outflows

The first committed outflow is for irrigation of Tracts 6 and 7 of RB NIS, and part of the left bank area in the old irrigation scheme (800ha) as both are out of the studied area. These outflows are estimated as a proportion of the total issues from the main reservoir, based on the command areas. They are 26 mcrn and 21 mcm respectively. The second committed outflow is for Bundala lagoon and for sanitary requirements in the Kirindi river. It is assumed that the drainage flows which are included in the committed irrigation discharge allocated for Tracts 6 and 7 and for part of the old area, will take care of it.

The uncommitted outflows from the scheme has been measured twice daily: along the Kirindi Oya river close to the mouth, and the drainage from tracts 5 on RB of NIS (Fig. 1). They are 28 mcm and 68 mcm respectively, therefore the total of uncommitted outflow reaches 96 mcm, which is the same value than that of irrigated crop consumption.

Closing the water balance with Remote Sensing images

Remote sensing was used to supplement field measurement to get a more complete picture of the area. A land use map was developed using Landsat images. The same images were also used to estimate evapotranspiration for a 24 hour **period.** using the SEBAL model (Bastiaanssen et al, forthcoming). Results fully confirm the above figures.

The aerial average evapotranspiration for 24 hours (ET_{24}) was estimated on the 19 th June 95 from the Landsat image, is 1.09 MCM, whereas the average value computed for 1998 amounts to 0.92 MCM per day. These two values are fairly close, and the 18% difference can be readily explained. The average value for June is 12% greater than the yearly average. Remote sensing snapshots tends always to overestimate the average because they are usually representative of the cloudless days which have a higher evaporation value than average. June is in the middle of the Yala cultivation season, whereas the annual average include periods of fallow for which irrigation is cut off and evaporation lower than for irrigated periods. It can be easily concluded that global results from remote sensing largely confirms the figures measured on the ground. More detailed analysis has led to the computation of ET„ with respect to land use. Values are reported in Table **3.**

Table 3. Estimated values of evapotranspiration ET 24hours **for** the 19th June 1995 (from SEBAL model)

Land use	ET 24 hours mm
Paddy field	4.5
Water body	5.4
Homestead (perennial vegetation)	3.8
Forest (perennial vegetation)	4.1

This remote sensing assessment demonstrates clearly that perennial vegetation evapotranspiration is quite important, about 4 mm/day which is **just** slightly less than that of measured for paddyfield. This is also consistent with the estimation of the water consumption derived from the water balance in 1998, an average **3.2** mm/day from a total of 1 187 mm. As the latter value includes direct interception, the net evapotranspiration for perennial vegetation is lower. For an interception coefficient of 15 % the net evapotranspiration in 1998 is reduced to 1052mm, i.e. 2.9 mm/day.

CONCLUSIONS AND PERSPECTIVES

Out of a total of 478 mcm of inflow from surface flows and rain, one fifth (95 mcm) is really beneficial to crops, the remaining part is split into drainage to the sea for 96 mcm and a deficit in run-off (non process depletion) estimated to be 184 mcm. To a certain extent the drainage flow can be reduced by improved management techniques and the use of recycling facilities. The water saved could be utilized for other uses of water or to extend the irrigation intensity and the command area.

The main finding of this study is that in humid or semi-humid tropical environments, non-crop vegetation (mainly perennial), is a significant factor in the design, management and performance assessment of water resource use. This was demonstrated at the Kirindi Oya study area where water consumption from non-crop vegetation averaged at the scheme level reaches 1200 mm/year, whereas paddyfields consume 1260 mm/year for a double crop. As a whole, non-crop vegetation represents 55% of the total evaporation in the area, whereas crop consumption accounts for only 28%. Moreover, much of this non-crop vegetation is beneficial.

In this kind of environment the classical efficiency approach, i.e. evapotranspiration minus effective precipitation divided by the diversion has little meaning compare to beneficial depletion divided by available water.

There is much more to be done in order to handle seriously the issue of perennial vegetation. Further studies will have to be carried out to investigate the questions that still need to be answered:

- To what extend non-crop vegetation is beneficial?
- What are the sub-class of non-crop vegetation and perennial vegetation, and how much water do these consume?
- What is a design of a reliable and simple means for managers to assess non-crop vegetation?
- How does non-crop vegetation in irrigated areas compare with that of non-irrigated area?
- How can designers, managers, consultants and researchers better take into consideration non-crop vegetation in design, management and performance diagnosis?

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