WATER PRODUCTIVITY – METHODOLOGIES AND MANAGEMENT

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Abstract

This paper presents definition, measurement and practical application of water productivity. Productivity of water is the physical mass of production or the economic value of production measured against gross inflow, net inflow, depleted water or available water.

In order to improve water productivity, TIP proposes a solution which focuses on: moisture stress tolerant crop varieties that produce more marketable yield per unit of water consumed, farm practices that optimize water use, management techniques that give farmers timely access to water. In the proposed solution, TIP uses "Tail – to- Mouth" approach to address problems of low water productivity

The approach requires that irrigation improvement intervention should start at the field level whereby farmers will be trained in agronomic skills to increase land productivity first before any physical irrigation infrastructure improvement. Experience has shown that the combination of rainwater harvesting and soil and water conservation techniques have doubled crop production, thus enabling farmers to re-invest on the land. As moisture is retained in the irrigated land, farmers will have a tendency of using less irrigation water, leaving extra water flow back to the river basin for other users downstream. Therefore water productivity increases with improvement in farming practices

Keywords: water productivity, water management, water stress tolerant crops, agronomic practices, water table, soil moisture content, irrigation scheduling

Introduction/Background

Livelihoods of many smallholder farmers in Africa are of low quality. Socio-economic conditions are generally a significant constraint to use land and water resources productively and sustainably, to generate a fair household income and to protect the resource base. There is also a shortage of accurate information about land and water management technologies.

Irrigated agriculture has many shapes, sizes and faces. These range from large storage dams, canal-fed surface systems to garden-level drip irrigation; from farmer managed to government managed; from supply-based water deliveries to those that respond to farmer demand. As irrigation is a large consumer of water, development in irrigation has profound impacts on basin-wide water use and availability. Yet, planning and execution of irrigation interventions often take place without consideration of other uses like domestic and industrial. One of the main reasons for restricted view on the part of irrigation experts is inadequate means to describe how irrigation water is being used. Irrigation efficiency is the most commonly used term to describe how well water is being used. But increase in irrigation efficiency does not always coincide with increase in overall basin productivity of water.

Irrigation can have a profound impact on nature, local communities and other users of water in river basins, that these consequences have been neglected when irrigation is being developed and managed. There is a need to better understand these linkages and influences and to evaluate options for developing and managing water more productively, for the benefit of all users in a river basin. Development actors have a challenge therefore to improve water productivity by employing tools, methodologies and processes that allow effective use of water. Low water productivity is common among smallholder farmers.

Reasons for low water productivity in irrigated areas include:

i) Uncontrolled expansion of irrigated land, using techniques/methods that waste water
ii) Absence of discharge measurement devices in the traditional irrigation schemes.
iii) There are no efforts from the smallholder farmers' part to apply for water rights from higher authorities.
iv) Leaving traditional irrigators to continue practicing irrigation on their own.

Problems encountered due to low water productivity

1. Gradual drying up of rivers in the tail end, thus causing environmental destruction of fauna and flora. Water application beyond root zone, not used up by plants but wasted. This causes difficulties to other users who are unable to access water for irrigation.
2. Growing number of water related conflicts in the river basins. Disruption of activities as a result of conflicts leads to low food production, which in turn lead to food poverty and income poverty.

Objective

The main objective of this paper is to share knowledge and experiences of methodologies that can raise water productivity in order to increase agricultural production as well as releasing water to other users.

The paper intends to answer the following questions:

- How can the productivity of water be enhanced through water management interventions?
- What are the appropriate designs, operational procedures for both large scale and small-scale irrigation systems
- What irrigation practices lead to real water savings in a river basin?
- How can evaporation be reduced?

Definitions

Irrigation efficiency:

Irrigation efficiency is a special case of the water use efficiency. It is the measure of efficiency for irrigation given specified boundaries. There are many ways of measuring efficiency, some of which are conventional and well known, others which are new and attempt to capture efficiency for the whole system and the temporal elements of efficiency. Unlike productivity (which has units), however, efficiency is expressed as a %, being a measure of net to gross water use or net days of irrigation to gross days of irrigation.

Irrigation productivity:

It is a measure of the economic or biophysical gain from the use of a unit of irrigation water in crop production and is expressed in productive crop units of kg/m^3 or $\$/m^3$. As the name portrays, this is the product that is obtained from the irrigated crop to which the diverted water was planned for. Here we just consider our product from irrigation process but do so in ways that capture the whole system of water use and re-use.

The water use efficiency: is a measure of efficiency of water use for a defined user type with specified boundaries, and is expressed without units (i.e. as a percentage) requiring the formulation of the net and gross amount of water utilised for the activity under study. This explains the efficiency of different uses/users (e.g. fisher people, irrigators) in an irrigation system of which there can be many and they may differ in demand of water for the same activity. We need to evaluate efficiency of water use by examining the nested users.

The productivity of water: is a measure of the economic, livelihood or biophysical outputs derived from the use of a unit of water. Such outputs are brick making, crop production, fishing, livestock watering etc. Units are jobs per m^3, $\$/m^3$, total biomass ($kg/m^3$), families per command area. The productivity of water in an irrigation system is more than what comes from the intended or unintended products within the total command area i.e. water diverted for irrigation system can be used for many other users e.g. domestic purposes, fishing, brick making etc. Water productivity is therefore a wider consideration of the products that comes from the diverted water for the irrigation system.

Methodologies

Improving water productivity whether under rain-fed or irrigated conditions requires first an increase in marketable crop yields for each unit of water transpired. Also necessary is a reduction of all outflows or "losses" (e.g. drainage, seepage and percolation) except crop transpiration and more effective use of rainfall, stored water and water of marginal quality. Loss reduction and water control are considered parts of basin –wide integrated resource management which gives essential role to institutions and policies in ensuring that upstream interventions are not made at the expense of downstream water users.

TIP'S EXPERIENCES

The Traditional Irrigation and Environmental Development Organization (known by its acronym TIP), is a non-profit making, non-governmental organization registered in Tanzania as a Trust since August 1999. TIP is governed by a Board of Trustees and is operating with support from major donors NOVIB (The Netherlands International Development Organization).

The Netherlands development organization NOVIB, supports TIP based on the Multi-Annual Plan (2002 – 2005) targeting rural development in the four (4) partner districts of Arumeru, Mwanga, Same and Lushoto.

Vision and Mission

TIP's vision is to be a reliable partner of local communities in their pursuit of rights to sustainable rural livelihoods, through a gender equitable access and control of land and water resources.

Its mission is to effectively contribute to the socio-economic development of men and women through traditional irrigation improvement in the context of sustainable agriculture and natural resource management.

TIP's general objective is to contribute to "increased agricultural productivity through improved traditional irrigation, land use management and water use efficiency with a gender perspective to contribute to poverty alleviation and food security".

Implementation process

TIP Package and approaches

In its mission of alleviating poverty, TIP has developed and delivered an integrated package of activities that comprises:

i) Irrigation and drainage improvement
ii) Participatory Land Use Planning.
iii) Organization development and gender mainstreaming
iv) Market access and agro enterprise development

The combined effect of these activities help Water User Groups achieve poverty reduction.

In order to properly implement its package TIP uses three approaches namely:

(a) The stepwise approach, which is participatory in character and a good tool for gender mainstreaming.
(b) Tail-to-mouth approach with economic bias concept
(c) The catchment approach; rather than looking at traditional irrigators only, all stakeholders within the hydrological catchment area (with a common drainage) are involved. The approach is commonly used to address river basin related problems.

Improving water productivity requires the use of two approaches namely tail-to-mouth and catchment approaches.

Case Study: Kileo Irrigation Scheme

Background of the scheme

Kileo Irrigation Scheme is located in Kileo Village in Mwanga District, Kilimanjaro region. Total beneficiaries are 600 smallholder farmers of Kileo Village. The total area under irrigation at present is 425 hectares, which is 25% of the total village area. But according to the project design, only 400 hectares were designed for irrigation.
The scheme abstracts water from Ghona River and is at the tail end. There are nine (9) other schemes upstream covering lowland areas of Marangu, Himo, Makuyuni and Chekereni.

There are two farming seasons. The long rain season starts in January up to May and dry season start in July through December. It is during the dry season when farmers apply irrigation and this has enabled them to plant and harvest twice per year. *The main crops that were planned during the Project design were maize and beans but recently various types of vegetables have been introduced such as watermelons and tomatoes.*

Present crop production

Maize: 2.5t/acre, Beans: 8.4t/acre, Watermelons 8t/acre.
The scheme received infrastructure improvement support from Traditional Irrigation Programme in 1993. Previous support from the Government was inadequate to cover all the necessary improvement requirements.

Problems of Kileo scheme related to irrigation efficiency and productivity

Although irrigation infrastructure was improved the scheme had the following problems related to irrigation efficiency.

i) The main canal and distribution canals were not lined. Therefore conveyance losses were high (confirming the old adage that agriculture is the most inefficient water user)
ii) Division boxes made 11 years ago needed rehabilitation, as there were water losses at the distribution points. Farmers had begun the work but it was going slowly.
iii) Due to lack of frequent training in water management farmers spent four (4) hours to irrigate one plot of 1 acre which is leveled! Later it was discovered that this situation was artificially created to benefit few (corruption).
iv) The diversion weir upstream of Kileo Scheme was wrongly designed and constructed because the weir crest level was unnecessarily high to the extent that all water in the Ghona river was diverted during dry season. Such a situation was a recipe for water related conflicts.

It was understood that immediately upstream of Kileo, the water User Group had the practice of diverting water not only for irrigation but for other non-agriculture uses particularly domestic – washing, cooking, watering animals, construction; you find water flowing in the canal 24 hours without strict scheduling. Figure 1 shows different water users abstracting water from Ghona River.

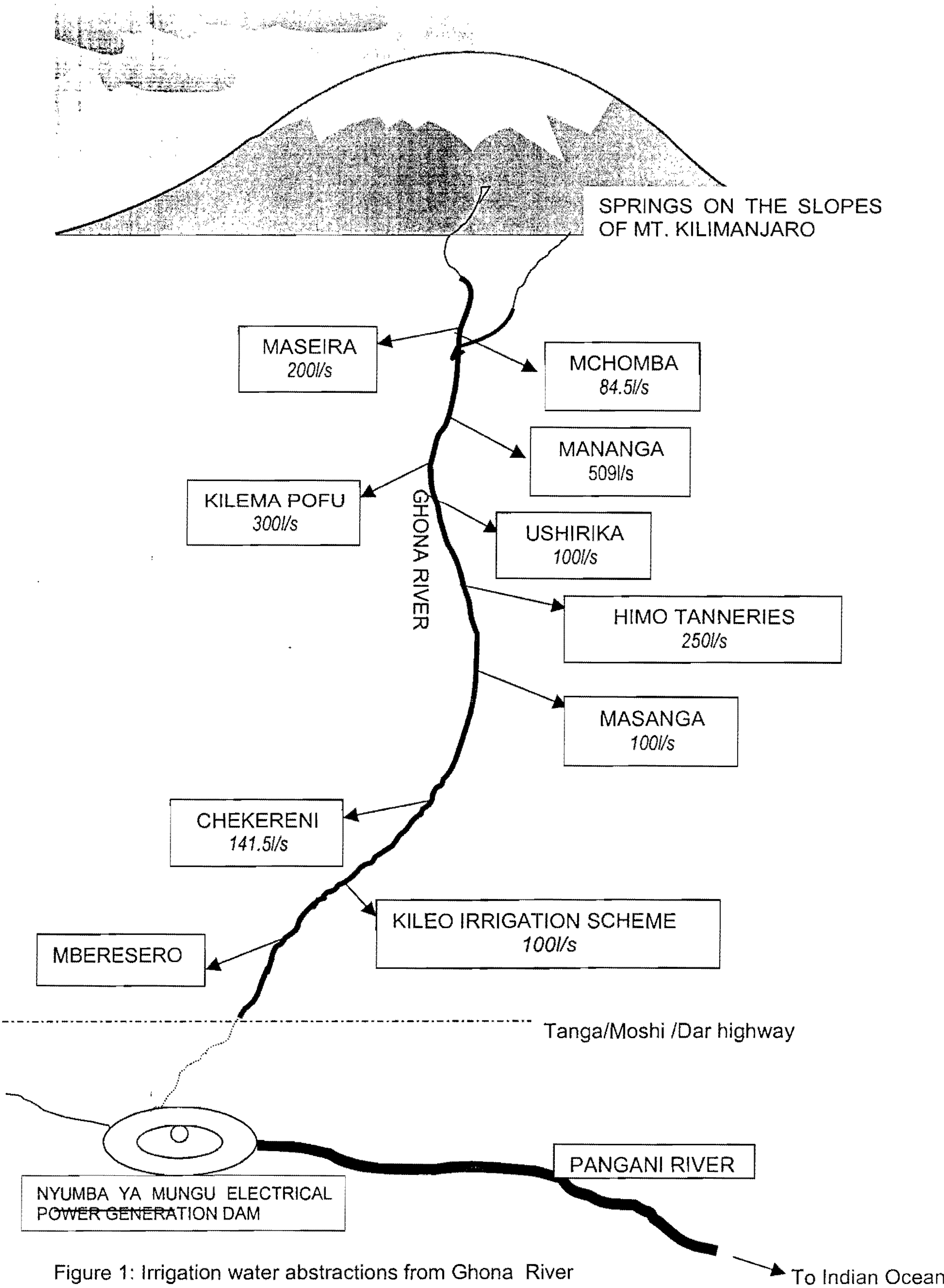

Figure 1: Irrigation water abstractions from Ghona River

i) Uncontrolled expansion of irrigated land created water scarcity situation among smallholder farmers.
ii) The scheme had no discharge measurement structure (something that is common to most irrigation schemes). Besides, during improvement stage, there were no efforts to apply for water rights from Pangani Basin Water Office (PBWO) because the governing body was non-existent. But of recently the scheme has acquired water right of 300l/s through TIP's mobilization and facilitation.

Critical problem facing this scheme was frequent water related conflicts resulting from incorrect allocation of irrigation water in Ghona river basin.

Use of TIP's approaches to improve water productivity

The Catchment approach

TIP using its catchment approach attempted to solve the problem of water distribution among stakeholders of Ghona River Basin.as follows:

i) Meetings were held between d/s users and u/s users to formulate a mechanism that will help distribute water among stakeholders in an equitable manner thus devoting more time for production activities.
ii) Inventory of all water users was done, irrigators and non-irrigators alike
iii) Water measurement structures were proposed for each scheme/project in order to know the abstraction amounts for each individual water user along the basin as per water rights.
iv) As a regulation Project irrigated area was reduced in times of water scarcity. This was necessary to ensure that river should not be dried at the tail end that led to Nyumba ya Mungu power generation dam.
v) Training of farmers in water management especially in field water application. Construction of irrigation infrastructure (weir, intake, canal lining, division structures, water measurement structures and cross drainage works form part of overall water management.)
vi) Training farmers in Operation and Maintenance of irrigation infrastructure. Practical application of the knowledge touched aspects of organizational strengthening of water user groups.
vii) Installation of canal spillway (side weir). Side weirs are located along the canal preferably at the initial stretch of the main canal to discharge excess flows back to the source (river).
viii) Installation of drainage system. Efficient drainage system allows water to flow back to the river system, thus allowing other D/S stakeholders access to water resource. Excess water on the irrigated land

TIP recommended establishment of Ghona River basin management Board that comprised stakeholders' representatives, with constitution, bylaws and regulations such as water right acquisition, which are binding. Composition of the Catchment Water Board and the proposed process to be followed for selection or election of its members is as follows:

- Chairperson
- Secretary
- Advisors for different sectors (forestry, water department and agriculture)
- Regional Secretariat (Regional Hydrologist).
- Councilors (2), one from each of the districts of Mwanga and Moshi Rural.
- Wards government representatives.
- Two Representatives of individual WUGs.
- Representatives from other collaborators including Pangani Basin Water Office and TIP

Functions of the Catchment Board include:

a) Formulation of Catchment Board constitution
b) Formulation of by laws safeguarding and management of water.
c) To provide training for stakeholders.
d) Formulation of procedures in water use and water sources management
e) Conflicts resolution
f) Participation in the mobilization of better water use.
g) To plan for better water management.
h) To participate in the formulation of national water policy.
i) Supervise conservation practices in the catchment.
j) Collection and keeping of catchment Board records and data.
k) Collection of water fee and coordinate its use.
l) Train stakeholders on the importance of water rights to water users and follow up on how they can be obtained.

Reasons for the apparent water scarcity in the river basin were attributed to:

- Inefficiencies in water management u/s, and d/s.
- Human activities that were destructive to environment like soil mining (where farmers in the catchment harvest all the grass and crop residues leaving the fields bare) and uncontrolled grazing.
- Kileo scheme and other schemes upstream did not have reliable irrigation schedule.

The measurement of irrigation efficiency was considered while water supply systems for domestic purposes were ignored.

NB: As water gets lost on its way to the field, farmers tend to abstract more water than they are allotted, thus creating scarcity for other stakeholders d/s the river basin.

Use of Tail to mouth approach with an "economic bias"

The Tail to Mouth approach requires that before embarking on physical irrigation infrastructure improvement, the farmers start improving the absorption capacity of their fields (tail end) and combat soil erosion. This means, application of suitable and recommended Soil and Water Conservation measures that includes: physical, biological as well as supplementary measures that retain soil moisture.
The approach is similar to irrigation design, wherein survey is done before deciding on the sizes of the structure, that designer starts at field levels through canals system to the intake, adding water losses encountered on the way. So the approach is rational and user friendly.

The physical measures includes stone terraces, cut off drains and earthen terraces (popularly known as <u>fanya juu</u> in Northern Tanzania) Biological measures are grass strips along the contour, live fences and tree planting. On farm works comprise activities such as land leveling, according to border/basin sizes. Borders capture rain without causing run off, hence increases soil moisture retention. Therefore it is recommended that farmers make the best use of rain to ensure that water diverted

In the irrigation improvement process, these activities do not constitute major capital investment. There is more software rather than hardware. That is why more training is done at this stage. When there is sufficient improvement of land management practices (land conservation measures done for more than 50% of the entire irrigated area), gradually the work proceeds in the direction of the water source (mouth) by improving the canals systems and making some more capital-intensive investments. When farmers start receiving more income (increased productivity) through improvements on their fields they are ready and able to re-invest the surplus they get on the land to get more income. This is what is referred to as the "economic bias" concept. Description of Tail to Mouth approach with its three stages is shown in Figure 2.

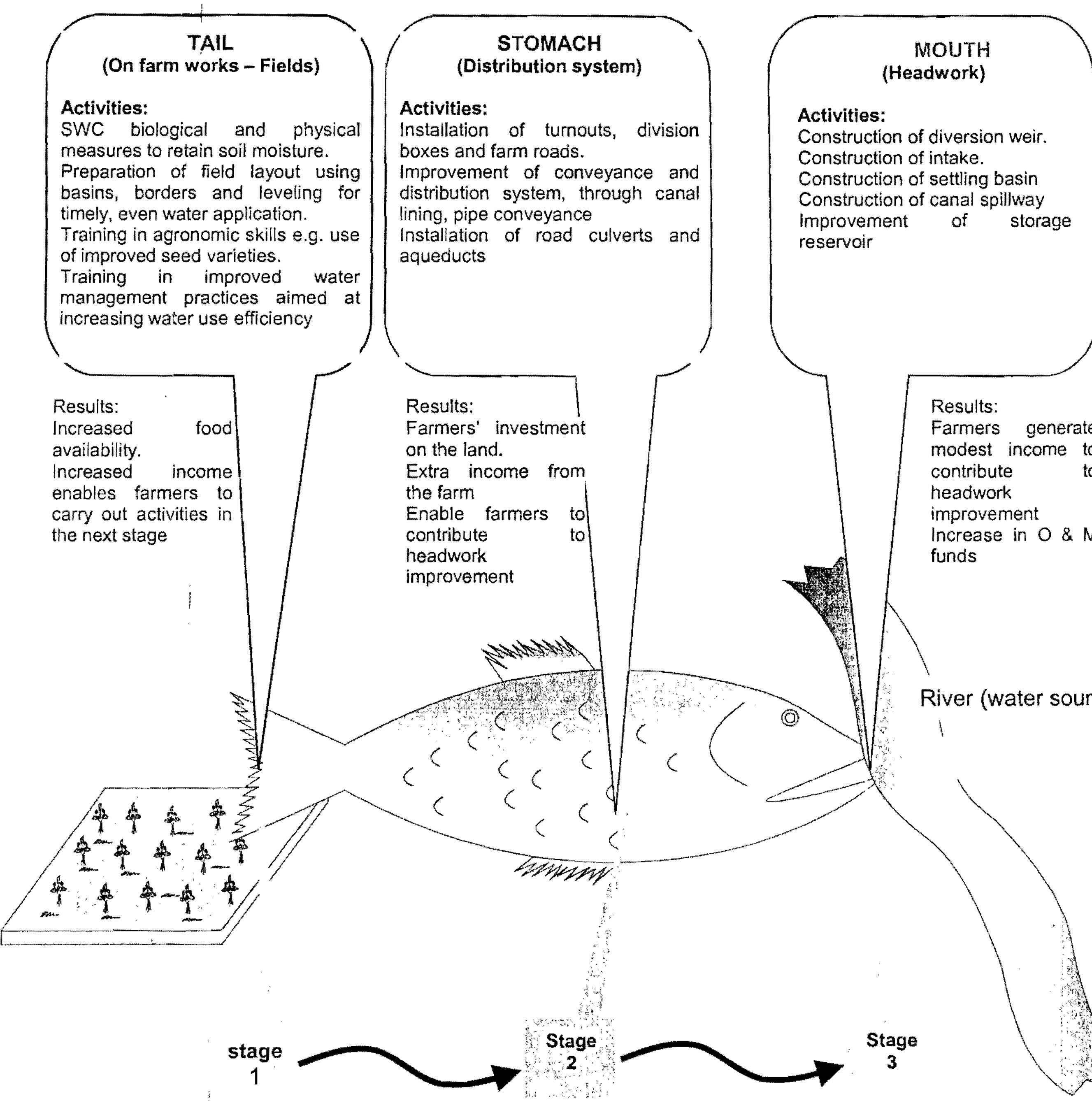

Figure 2: The Tail – to - Mouth Approach

Factors affecting irrigation water productivity

a) The economic utilization of water depends on the following factors:

i) Conveyance and distribution efficiency

ii) In simple terms how efficiently have you brought the irrigation water to the field? Water productivity increases with increase in irrigation efficiency.

iii) Agronomy: the soil fertility status affects the product quality and quantity. Production skills and techniques ultimately determine the quantity of products. With improved agronomic practices, there will be an increase in water productivity.

iv) Climatic factors such as temperature, wind, rain influences productivity either positively or negatively.

v) Irrigation scheduling: Depending on whether the system used is supply-based or on demand, a situation may arise when the irrigation water depth applied exceeds crop allowable moisture deficit resulting in deep percolation loss. Horticultural crops require shorter irrigation intervals and hence tend to use excessive water. On the other hand grains such as corn (improved seed variety) and millet can tolerate moisture stress for a long period of time.

The combined effect of four factors named above results in desired description of water productivity.

b) Indicators of low productivity:

i) Irrigation water depth in mm that is beyond the root zone

ii) Water application in mm/ period that is not following standard crop water requirement.

Area designed for irrigation not put under profitable use and yet releasing the same design discharge from the intake. Referring to Projects that are operating below capacity. For a project a capacity means a number of **tons/acre** of a particular crop produced.

Methods of raising water productivity

Following TIP's catchment approach, in farmers' fields, higher water productivity requires changes in crop, soil and water management. Strategies include:

i) Selection of appropriate crops and seed varieties (from indigenous to improved seeds).

ii) Use of improved planting methods (e.g. on raised beds), planting in rows for proper crop spacing (cropping intensity) and application of pesticides.

iii) Land preparation using different methodology such as minimum tillage,

iv) Synchronization of water applications with the most sensitive growing periods (deficit, supplemental, or precision irrigation) and improved drainage for water-table control

v) Irrigation scheduling that matches with crop water requirement.

vi) Using pipe conveyance system whenever possible instead of open channel to reduce water losses.

All cultural and agronomic practices reduce water evaporation such as variable row spacing and application of mulches to improve soil moisture retention.

Options for improving water productivity include better land use planning, use of medium term weather forecasts, improved irrigation scheduling and use of various sources of water.

Findings/Results

i) Water productivity depends on the initial moisture content of the soil. Occurrence of rains will affect the overall water productivity value as one will tend to apply less water depth just after rainfall.

ii) Water table levels within the root zone affects soil moisture and hence water productivity

iii) Amounts of fertilizer can influence the estimated water productivity value because of plant nutrients uptake.

iv) Seed varieties and crop protection techniques play crucial role in determining the quantity of yields. To increase productivity high yield seed variety should be selected. Switching from high- to less-water-consuming crops, or switching to crops with higher economic or physical productivity per unit of water consumed.

v) Cropping calendar should be determined for a particular climate setting e.g. changing crop-planting dates to match periods of less-evaporative demand.

vi) Adding storage facilities and releasing water during drier periods increases productivity. Storage takes many forms including impoundment in reservoirs, groundwater aquifers, and in small tanks and ponds on farmers' fields.

vii) Reuse of return flows through gravity and pump diversions help increase irrigated area. This means that water loss from Irrigation Project is not lost to the larger system because of the possibility of reuse. Boundary conditions have to be defined when describing water losses.

viii) Efficient irrigation technology determines the magnitude of water productivity as shown in Table 1.

Table 1. Water productivity changes when shifting from conventional surface irrigation to pipe conveyance system in Kwa Mlombola Water User Group in Mwanga District

Crop	Surface irrigation productivity (kg/m3)	Water productivity using pipes (kg/m3)
Maize	0.4	1.1
Cabbages	6.2	9.8
Tomatoes	4.9	7.9
Onions	4.9	6.2
Irish potatoes	10.9	17.5

Source: TIP Monitoring and Evaluation Report June 2004

The way forward

i) Improve domestic water supply system in the rural areas. This creates less reliance on canal water for domestic uses. Farmers want to have water in the canal running for 24 hours for washing, cooking, brick making and car washing.

ii) Conduct intensive water management training for all water users in the river basin and establish a river basin board.

iii) As a water management plan, install water measurement structure for every water user; maintain records of water flows in the river as well as in the canals along the same river basin. Make sure that each abstraction is made as per water right.

iv) Install piezometers at suitable locations to monitor water table fluctuations that affect crop water requirement and consequently productivity.

v) Efficiency should not only be considered for agricultural water uses but also for other sectors in the river basin.

vi) Train farmers in agronomic skills in order to improve land productivity.

vii) Design systems based on water productivity approach instead of solely basing on irrigation efficiency, which is inadequate to describe irrigation system performance

Need for further research

Due to complexity in the Catchment management, there is a need to develop a user-friendly tool for water allocation at Catchment Management Agency level or develop a decision support system that takes into account of initial soil moisture, water table levels, soil fertility, crop type, irrigation efficiency and drainage conditions. There is also a need to conduct study on the effect of using labour intensive methods on one hand versus mechanization on the other hand in the process of improving water productivity

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