Food and Agriculture Organization of the United Nations

Field guide to improve water use efficiency in small-scale agriculture

The case of Burkina Faso, Morocco and Uganda

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Contents

Foreword

The role of irrigation in gearing agriculture development towards a broader economic growth is undeniable. Accordingly, irrigation is growing into key operational strategy for governments and their agencies to increase agricultural productivity, thus combatting food insecurity and boosting overall growth. While agriculture absorbs rural workforce, generates income and increases food security, it has become the most important driver in freshwater exploitation. The rapid expansion of water demand leads to the generalized phenomena of imbalance between water supply and water demand. This increasing pressure on water resources urges enhancing water use efficiency.

Water use efficiency has a significant role in addressing the challenges faced by the agricultural water use. While irrigation can increase yields of most crops by 100 to 400 percent, water resources remain limited. By 2030, irrigated land in developing countries will increase by 34 percent, while the amount of water used by agriculture will increase by only 14 percent. Increasing food production with less water, particularly in countries with scarce water resources, is one of the major challenges. Beyond the inevitable effect of water use efficiency on addressing these challenges, it is also effective to adapt to climate changing.

Enhancing water use efficiency requires actions at all levels, from agricultural practitioners to scheme managers, and up to the policy-makers. The objective of this Guide Book is to show practical measures to improve water use efficiency in small-scale agriculture based on case studies from Burkina Faso, Morocco and Uganda. The Book not only presents applicable water use efficiency measures, but also guide the readers through their real-term implementation.

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Introduction

The challenges of agricultural production that can be addressed by efficient resources use are numerous, e.g. the reduced water loss helps keeping up with the increasing demand for food. Farming is not only about producing crops with the highest possible yield, but also about improving the production efficiency to enhance profitability, protecting soil and water resources for long-term sustainability, and making production less demanding thanks to new technologies and up-to-date information. Farmers play an important role in the overall success of an irrigation scheme. The quality of their efforts in saving water and increasing crop yields greatly contributes to the sustainability of their production, their income, livelihood and food availability and affordability for their community.

Irrigation management is a complex task that requires harmonized planning at many levels. Furthermore, decisions should be based on locally collected data and experiences about how the different elements interact at different levels. There is, however, no universal solution that can be applied to all farms. Each irrigation scheme and each farm require different combinations of practices, and farmers need to understand how the different options affect their farming outputs. Changing irrigation practices might have high additional costs to be recovered by the benefits, or slight changes in irrigation might have significant effect to increase yields or profitability.

This Field Guide is addressed to agriculture practitioners and researchers. Practitioners may be irrigation scheme managers, extension services, country level agency representatives, water user associations, or anyone interested in improving water use efficiency (WUE) through evidence-based guidelines. It provides practical information on irrigation management in open-canal systems to help enhancing the efficient use of water.

The Guide draws its content from the fieldwork, protocol-driven data collection and analysis of production practices in three countries, namely, Burkina Faso, Morocco and Uganda, with the objective to develop the most fitting improvement practices that have a unique combination of water use efficiency measures. The evaluation of the proposed water use efficiency measures took three years to be fine-tuned and mainstreamed into best practices in order to minimize risks and maximize benefits.

While the Guide provides complete set of instructions to improve water use efficiency in order to reach optimal irrigation practices, the successful outcome still depends on the farmers' willingness to embrace and adopt the recommended measures. The Guide holds in evidence that farmers are often constrained by available resources to improve their practices in terms of budget, inputs or labour. In order to take these issues into account, the recommendations are limited on practical measures, which can be followed by farmers without requiring additional resources.

The focus areas of the improvement measures are the following:

- Inspection of the hydraulic structures owned and/or operated.
- Operation and maintenance of the irrigation systems and the hydraulic structures.
- Irrigation water monitoring and quantification of the available water resources.
- Adjustment of irrigation schedule to the assessed water requirement.

Irrigation types and issues of development

The world's total irrigated area is around 324 million ha, of which 280 million ha (86 percent) is irrigated by surface irrigation. In Africa, the irrigation potential is massively unexploited as only 5.8 percent of the cultivated lands are irrigated. The irrigation systems mostly rely on surface water, only 19.2 percent of the lands are irrigated by groundwater. Also, 95 percent of the lands are irrigated with surface irrigation in Sub-Saharan Africa. However, surface irrigation is characterized by the lowest efficiency of all; yet at least 40 percent of the water does not reach the fields due to the water loss along the conveyance. In order to maximize the benefits of surface irrigation systems, water use efficiency is one of the key factor to improve.

Irrigation management normally consists of four key aspects through which the irrigation can be appraised: water balance between water resources and crop water requirement, institutional system, conveyance/engineering system and delivered water service. water use efficiency can be tackled from each aspect, but traditionally the measures address the water balancing and the engineering system at scheme and farm levels. The types and designs of the irrigation system substantially determine the applicable water use efficiency measures, e.g. the small-scale irrigation schemes often show large irregularities in spatial and temporal water demand, while matching irrigation turns to water demand in large-scale system is more predictable. The typologies of irrigation schemes can be distinguished as shown in Table 1.

The piloting approach selected representative schemes in Burkina Faso, Morocco and Uganda, reflecting on the main typologies of irrigation systems in Africa. The selected schemes are Ben Nafa Kacha in Burkina Faso, Haouz-Sector 3 in Morocco and Mubuku in Uganda. The three small-scale schemes are all formal schemes established in governmental programmes. The open-canal systems rely on surface water sources, while water conveyance is by gravity and surface irrigation methods are applied at farm level.

Table 1: Typologies of irrigation schemes

Typology	Types
Origin	Formal Informal
Scale	Small-scale Medium-scale Large-scale
Water Source	Surface water Groundwater Mixed water source (ground- and surface water)
Irrigation delivery method	Open-canal system – surface irrigation Pressurized irrigation system
Irrigation distribution method	Surface irrigation system: furrow, basin and border Sprinkler irrigation system, including set system and flexible systems Micro-irrigation (localized) including drip, spray, bubblers etc.
Water conveyance	Gravity-fed conveyance Pumping system (fuel, solar, renewable energy, wells, tub-wells, electricity etc.) Combined systems
Type of installation	Solid installation Semi-permanent installation Portable/flexible installation
Type of control	Supply-driven Demand-driven
Management	Public ownership Privately ownership Public-private ownership
Cropping system	Multicropping Mono-cropping Paddy rice system

Ben Nafa Kacha irrigation scheme in Burkina Faso

Background

Ben Nafa Kacha irrigation scheme is located in Sourou, western part of Burkina Faso. The small-scale irrigation scheme occupies 275 hectare area cultivated by 247 farmers. Agriculture is the only sector to provide work and income for the rural population in the area. Close to the border with Mali, the farmers' only opportunity to support their families is to split the production partly to commercial purposes and to subsistence. Available water resources provide good conditions for irrigated agriculture, therefore, the region became one of the country's strategic area for agricultural production.

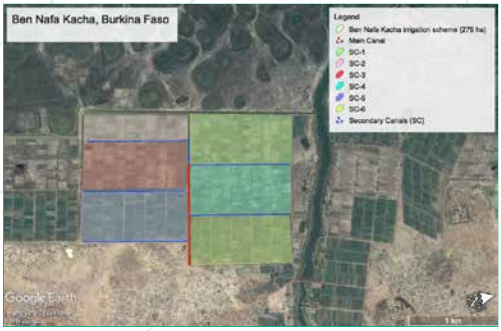
Irrigation system design

The irrigation water is sourced from the Sourou River by a large pump system (3 pumps with 300 l/s capacity per each). To supply the open-canal system with water, the pumps are operated according to a fixed schedule - 2 pumps operate simultaneously for 12 hours per day while the 3rd pump is a back-up. The water is lifted by Archimedes screws into the main canal that conveys water by gravity to 6 secondary canals; and the secondary canals provide water to unlined tertiary canals through 'module à masques' offtakes.

Figure 1: Ben Nafa Kacha irrigation scheme in Burkina Faso

Source: CIHEAM BARI, 2018

Figure 2: Schematics of Ben Nafa Kacha irrigation scheme



Source: CIHEAM BARI, 2018

Figure 3: Archimedes screws for water withdrawal

©FAO/Abdelouahid Fouial

Figure 4: „Modules a masque" for water distribution between the lower level canals

©FAO/Abdelouahid Fouial

Irrigated agriculture

The cropping pattern consists mainly of onion, maize and paddy rice irrigated by furrow or basin method. The agricultural production is distinguished into two seasons (humid and dry seasons), while there is only one irrigation campaign from October to April. Each farmer cultivates an average one hectare land in multi-cropping system, and each farm is irrigated by 1 or 2 irrigation turns per week, except rice, where the filling of the basins lasts a month in October. The irrigation is managed by the local Water User Association (WUA) who is responsible for the operation and maintenance of the hydraulic structure, and the operation of the pumps and water distribution amongst the secondary canals. According to the established discharge record, the average daily water supply is sufficient to meet the maximum crop water requirement. However, farmers often experience water shortages and waterlogging due to inadequate irrigation practices. Although the water supply is sufficient, the water use efficiency and water distribution-application should be further improved. The analysis identified temporal water oversupply in terms of duration and frequency of irrigation, while the applied water amount is not adjusted to the crop development stages. It also identified cases of water shortage occurred due to the difference between the water requirement per crop development stages and the fixed irrigation turns.

Water use efficiency

Due to pumping, the main concern of the scheme management is the varying electricity price, which significantly increases the expenses taken care by the WUA. The majority of the operating costs is borne by the energy use to lift water from the River to the Scheme, and the cost is transmitted into farmers' annual fees. Increasing water use efficiency and improving water distribution-application are crucial then to recover these costs.

Haouz-Sector 3 irrigation scheme in Morocco

Background

Haouz-Sector 3 Irrigation Scheme in Marrakech-Tensift region is important in terms of agricultural production. Due to growing population, agriculture became strategic sector to absorb rural workers and generate income in the region. The semi-arid basin is already overexploited, although water is at the core of further socio-economic development. Other sectors compete for water resources such as urban growth, industrial activities and tourism, thus requiring frequent reallocation according to their changing water demand. In addition, Haouz is one of the country's most complex sites in terms of hydraulic network due to its continuous restructuring and development.

Irrigation system design

In Haouz-Sector 3, water is diverted to the main canal from Hassan I-Sidi Driss Dam and delivered by gravity through the secondary canal S2P1R3. Water is distributed directly to the farms through tertiary and quaternary canals. The slope of the plain area is not sufficient to convey water, so the system design applies mounted structures. The suspended main, secondary and tertiary canals are made of concrete; therefore, water loss is considered only due to evaporation and leakages. At farm level, water is distributed through earthen canals (not lined), therefore, larger amount of water is lost due to deep percolation, canal erosion, water evaporation, and overtopping. Therefore, farmers hold key role to decrease water losses thus tackling the emerging water stress in the area.

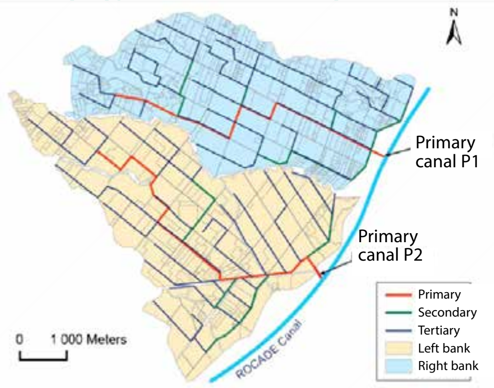
Figure 5: Haouz-Sector 3 in Morocco

Source: CIHEAM BARI, 2017

Irrigated agriculture

Apart from cereals, analysis involved olive experiments as the most produced crop in the region, making up to 78 percent of the irrigated area. Since the wheat crop cycle is longer (180 days from October/November) than the short-

Figure 6: Schematics of Haouz-Sector 3 irrigation scheme



Source: CIHEAM BARI, 2018

Figure 7: Measuring olive trees in Haouz-Sector 3

©FAO/Fethi Lebdi

period varieties, efficient irrigation – focusing on appropriate distribution – is a key factor to reach high yields.

Water use efficiency

In general, the area is extensively hit by severe drought, making the production and irrigation extremely difficult. Water scarcity is becoming more frequent and durable, and should, thus, be addressed by better irrigation practices. In light of the exacerbating water scarcity, the efficiency of irrigation water should be increased as possible and supply should carefully match crop water requirement. Currently, this water balance approach is missing and farmers are in lack of monitoring tools.

Mubuku irrigation scheme in Uganda

Background

Mubuku Irrigation Scheme in Kasese is promoted as a high priority area due to its excellent climatic conditions for agriculture. The Scheme was established as part of a governmental programme to promote productive use of the water resources. As the country's water potential remains largely unexploited, establishing small-scale irrigation schemes is a strategic pathway to decrease the national food insecurity, creating workplaces for rural population and to reduce the import dependency. The Scheme consists of 540 hectares of agricultural land cultivated by 167 farmers, of which an investigated Phase II consists of 254 hectares shared between 56 farmers.

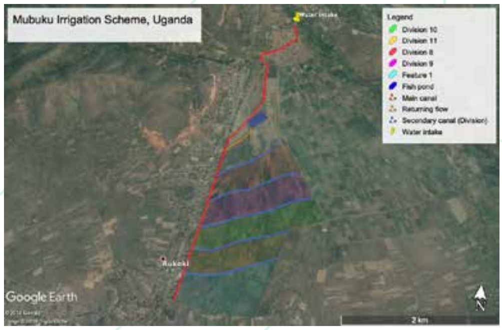
Irrigation system design

Phase II is supplied by Sebwe River through an open-canal and gravity-fed system. The main canal diverts water by gated intake into 5 Divisions (secondary canals), and each Division conveys water into tertiary canals. The intakes/offtakes are sluice gates between main and secondary, secondary and tertiary level. Down to tertiary level, the canals are lined and equipped with drop structures to reduce the velocity. For environmental purposes, a small capacity storing pond ("fish pond") is

Figure 8: Mubuku Irrigation scheme in Uganda

Source: CIHEAM BARI, 2018

Figure 9: Schematics of Mubuku Irrigation Scheme



Source: CIHEAM BARI, 2019

regulated at the entry stretch of the canal. As one of the major constraints of the design, the system does not have exit for water, thus, excess water is conveyed to other irrigation schemes through drains.

Figure 10: Intake gate of the Mubuku irrigation scheme

©FAO/Eva Pek

Figure 11: Returning flow from the fish pond

©FAO/Eva Pek

Irrigated agriculture

Farmers are tenants of the lands with 8 acres average field size (around 3.2 ha) under long-term lease contracts. The typical cropping pattern includes primarily rice, maize, onion; then tomato, beans and mango. There are two seasons in the year: humid season and dry season through which the irrigation is continuous. The analysis involved rice, maize and onion, and found a significant water oversupply during the crop development stages. It also found that water distribution amongst Divisions is not equal, therefore, farmers' irrigation practices vary according to the temporal water availability. Consequently, some farmers suffer from water shortage – particularly in downstream areas – and some farmers over-irrigate their plots.

Water use efficiency

Due to the currently released high discharge and the lack of exit at the tail end of the canals, waterlogging occurs around distribution boxes and at the tail end of the Divisions. Since excessive oversupply is as harmful as water shortage, increasing the efficiency of irrigation management is essential. In order to match crop water requirement with water supply, discharge measurements are essential. Another identified issue to take into consideration is the lack of water use adjusted to the optimal level of inputs (fertilizer, pesticide, and herbicide). The high discharge and the water oversupply accelerate the agrochemical leaching, which causes production losses, unnecessary expenses, and contaminated water in the drains.

What is water use efficiency?

Water use efficiency is the ratio of the water used effectively to irrigate the crops (water used by the crops) and the water entering the irrigation scheme. This term describes the effective water loss that occurs during the conveyance in the system, through the distribution canals, as well as in the farms. In other words, not all water withdrawn reaches the root zones of the plants, since part of it is lost during conveyance and in the fields. The reasons of this water loss through conveyance are numerous; it can be evapotranspiration, deep percolation to deeper soil layers, seepages, overtopping, bushes and weeds, runoffs, leakages and cracks, deteriorated hydraulic structures, etc. Some of the reasons can be effectively addressed by water use efficiency measures such as the maintenance of hydraulic structures, the lining and profiling of canals or the control of water supply. In addition, significant water losses can occur in the field if farmers do not take preventive actions. Surface runoff and deep percolation to soil layers below the root zone are the most common form of on-farm water losses.

Water use efficiency (%) at scheme level is the part of the withdrawn water which is used effectively by the plants. It can be divided into conveyance efficiency and field application efficiency. In other words, the conveyance means the losses through transportation, while the application shows the uniformity of distribution to the field.

Figure 12: Undesired vegetation (weeds) around the hydraulic structures

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Figure 13: Widened and deteriorated earthen canals

©FAO/Abdelouahid Fouial

Figure 14: Abounded quaternary canal filled with sediment

©FAO/Abdelouahid Fouial

Figure 15: Large-size drains

©FAO/Eva Pek

Figure 16: Flow chart of water use efficiency

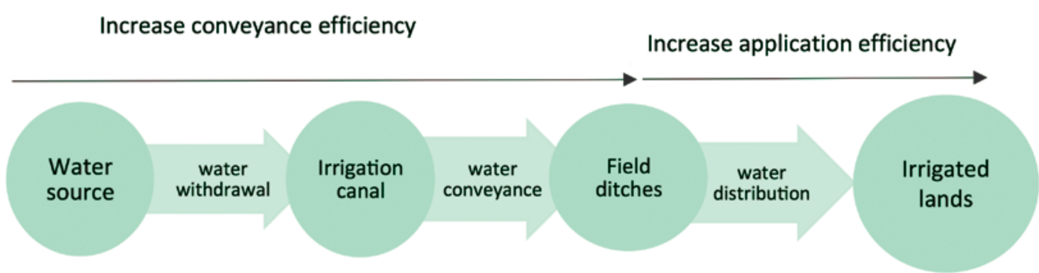


Table 2 and 3 provide indicative values of conveyance and field application efficiencies by irrigation system type.

Table 2: Conveyance efficiency of different type of adequately maintained canal

Conveyance efficiency	Earthen canals			Lined canals
Soil type	Sand	Loam	Clay	
Canal length				
Long (> 2000 m)	60%	70%	80%	95%
Medium (200–2000 m)	70%	75%	85%	95%
Short (<200 m)	80%	65%	90%	95%

Source: FAO - Irrigation Water Management, Training Manual 4.

Table 3: Indicative values of the field application efficiency

Irrigation methods	Field application efficiency
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

Source: FAO - Irrigation Water Management, Training Manual 4.

However, these indicative values consider optimal conditions, which assume adequately maintained hydraulic structures, sufficiently controlled water, absence of extreme climatic events, etc. After estimating the efficiency values of both conveyance and field application efficiency, the overall water use efficiency can be calculated with the following equation:

E = (ec x ea)/100, where
e= Water use efficiency (%)
ec= conveyance efficiency (%)
ea= field application efficiency (%)

Why embrace water use efficiency?

Thinking about water use efficiency, water saving will most frequently come into mind, although water use efficiency has several other aspects and effects. The major benefits of water use efficiency measures for small-scale irrigation are:

- Water saving and equal distribution between users.
- More production per unit of withdrawn water.

Moreover, the contribution of water use efficiency techniques to the overall environmental sustainability of the agricultural sector should not be underestimated. Faced with an increasing population, agriculture requires the identification of sustainable practices in order to ensure food security while at the same time improving its environmental impact. Notwithstanding the need to formulate policies and recommendations to deal with such challenges, the implementation of tailored water use efficiency measures in small-scale irrigation is important to address environmental sustainability and agricultural production.

Water saving and equal distribution

Water saving is the direct result of increased water use efficiency, which is not only for environmental purposes, but also to provide options for:

Drought preparedness by reducing water losses in Haouz-Sector 3

Morocco is currently experiencing severe droughts, and consequently water scarcity. The situation exacerbated in 2017, when irrigation-cease was introduced in order to prioritize water use amongst sectors. Water use efficiency measures have multiple impact when water is scarce; therefore, the water saving and the most efficient distribution amongst farmers and crops become essential to reap the greatest benefit per drop. Water saving, thus, helps avoiding the complete production failure and the adverse effect of the water shortage.

- Water storage and allocation to avoid water shortage in dry seasons.
- Extension of irrigated area.
- Reach of water to downstream farms.
- Other use of water such as livestock and fish ponds.
- Reduce flooding, waterlogging and soil erosion.
- Energy saving in case of pump use.

Even those irrigation schemes that are rich in water resources are often hit by temporal water shortage. If the water amount is not distributed adequately and equally over the season, the benefits of water shortfalls. Particularly those farmers who are affected by inefficiencies due to design problem are continuously exposed to poorer water distribution. This inequity can lead to conflict amongst water users then.

To understand how different issues of water saving and equal distribution evolve from the situations and conditions of given irrigation schemes, examples are presented from the country cases.

Energy saving through enhanced Water use efficiency in Ben Nafa Kacha

The main canal in Ben Nafa Kacha is supplied with water directly pumped from the Sourou River. Regardless of the crop water demand, the pumps operate in fixed schedule. In less-consumptive periods, when the crops do not require high amount of water or the soils are saturated, water is conveyed directly into the drains and back to the River. There is no flexibility with the irrigation schedule to control water supply through management rules. There is also no storage facility for the pumped water. Since the energy cost is transmitted into water fees, the farmers expenses remain high due to the extensive pumping, while a large amount of water is not utilized. Water use efficiency measures help controlling the water supplied and providing options to sustainable allocation. As such, not only water is "saved", but the cost of electricity bills is significantly reduced and water for alternative use is provided.

Creating equity between upstream and downstream farmers in Mubuku

Mubuku has sufficient overall water supply in both seasons; only temporal water shortage is experienced when the fixed irrigation schedule does not allow irrigating timely. However, water distribution needs improvement over the season, among the Divisions and among the farmers. Some farmers experience frequent water shortage, while others – particularly at the tail of the divisions – suffer from waterlogging. Water use efficiency measures allow for more equal distribution between upstream and downstream farmers through revised irrigation scheduling and deployed discharge measurement system.

More production per unit

Water use efficiency measures have direct impact on yield and on-farm economics through improved productivity, thus, generated income. Appropriate water management and good irrigation practices can bring a wide range of benefits, such as:

- Reduced production cost due to optimized input use.
- Increase in harvested yields.
- Higher quality of outputs.
- More flexible time of harvesting thus better market positions.

The case study of Uganda illustrates the negative effects of large water supply whereas the farmers apply more than the required water due to available high discharge and frequency of irrigation turns.

Mubuku Irrigation Scheme – Uganda

The irrigation turn in Mubuku Irrigation Scheme is scheduled in fixed rotation; and farmers receive water every 3rd day with the maximum design capacity of the tertiary canals. This can reach 70 to 90 l/s discharge during long hours. The high discharge causes a damage to the profile of the unlined tertiary canals to the extent that most of them are becoming too wide to efficiently distribute water to the fields. Larger flow is required in order to reach sufficient uniformity of water applied in farms. The parts of the farms close to the tertiary canals become oversaturated, while the high velocity moving along the furrows ripples and erodes their walls and bowls a large amount of organic debris into the drains. In addition, water flow causes agrochemical and nutrient leaching, soil erosion and damage of furrows. A large part of the purchased and applied agrochemicals ends up in the drains and dissolves in water. Apart from the economic loss, water quality significantly declines, and irrigation water becomes contaminated from the chemicals. In order to avoid these consequences, the water flow should be regulated by decreasing the water discharge becoming shorter, but with more frequent irrigation turns.

Water use efficiency measures for improved irrigation practices

The Guide attempts to present a step-by-step approach for improved irrigation practices at small scale derived from the pilot cases of Burkina Faso, Morocco and Uganda. However, the presented combinations of water use efficiency measures are not universal as farms have commonly unique conditions with specific cropping pattern that can vary over time. The water use efficiency measures can be implemented in many ways, but they should be flexibly applied to address unexpected concerns. To this end, the Guide demonstrates both O&M and management options through water use efficiency measures to inspire irrigation practitioners to think further.

The Field Guide is built on the following blocks:

- introduction of a wide range of water use efficiency measures that can be applied in irrigation schemes while providing a stocktaking exercise;
- demonstration of different combinations of water use efficiency measures to establish improved irrigation practices through country cases; and
- promotion of the key role of water monitoring for improved yields.

The Guide provides more than just an instruction material for practitioners. It offers a great potential for exchange of ideas among similar types of irrigation schemes and learning from others' experiences. Non-traditional learning of improving water-management is an iterative exercise where scheme managers are also invited to draw out a development and modernization plan from obtained experiences and practices.

Before starting: taking stock

Even if the presented water use efficiency measures are designed to be inexpensive and applicable for farmers, it is always recommended to take stock before embarking on any activity. By the rule of careful planning, the first step is to identify what works and what does not. Therefore, this section compiles an inspection log to appraise the current status of the irrigation system from the perspective of water use efficiency. The inspection is recommended to be repeated regularly, but at least before each irrigation campaign.

Water use efficiency on-farm: Inspection log for open-canal systems

*To be completed by farmers

------------------------------------ Date --------------------------------- Name

I. Farm information			
Status of the farm	New construction:	Rehabilitated:	Other:
Ownership	Tenant:	Land owner:	Other:
Production purposes	Commercial:	Household:	Other:
Size of the total area		**Location of the area**	
Irrigated land from the total area		**Main crops**	
Water source	Surface:….. Groundwater:…..		

II. Checklist

1. Water source· Is the water supply guaranteed by the scheme management?

- Does the water source supply sufficient water amount?
- Does the water source supply only your scheme?
- Does the water supply keep constant and stable until it reaches your farm?

2. Irrigation Scheme operation and maintenance

- Is there regular maintenance work carried-out by the scheme management?
- Are the canals cleaned-up before irrigation seasons?
- Are the hydraulic structures of water withdrawing (gates, pumps, etc.) checked, maintained and fixed before the irrigation season?
- Are the offtakes (gates, "modules a masques", etc.) checked and maintained before the irrigation season?
- Are the other hydraulic structures (drop-down structures, weirs, parshall flumes etc.) checked and maintained before the irrigation season?
- Are the canal bottoms, banks, joints checked and fixed before the irrigation season?
- Is the irrigation management able to act fast in emergency case?

If you provided some negative answers, please consult with your extension service or scheme management.

3. Farmers' irrigation management

- Are every part of your farm and the hydraulic structures accessible?
- Do you check your irrigation system regularly?
- Do you have the devices, tools or machine to repair your hydraulic structures?
- Do you carry out weeding, bushing regularly?
- Are your canals and hydraulic structures free from siltation, debris, solid waste or sediment?
- Do you maintain and repair your offtakes (gates, module a masques, distribution boxes etc.) to efficiently convey water?
- Do you check and fix the cracks on the canal banks, bottoms?
- Are your offtakes sufficient to control water?
- Is your irrigation system free from leakages and water loss?
- Do your tertiary and quaternary canals supply water uniformly across your farm?
- Do you have any devices or structures to monitor your water discharge?
- Can you turn your irrigation system off manually during rain or leakage?
- Do you keep the drains clean to convey excess water?
- Can you ask for technical assistance regarding your irrigation system?

If you provided some negative answers, please take actions and apply water use efficiency measures to improve your irrigation practices.

4. Irrigation scheduling and irrigation application

- Do you follow the pre-defined irrigation schedule?
- Is your system designed according to the maximum discharge?
- Do you consider the maximum design capacity of your canals when controlling water discharge?
- Do you know the application discharge/rate of your system?
- Do you follow the crop water requirement at irrigation water application?

Comments

- Do you monitor the climatic conditions such as rain, wind and temperature?
- Do you keep record of the historical water use?
- Can you ask for additional water amount in case of increased water demand?

If you provided some negative answers, please take action and apply water use efficiency measures to improve your irrigation practices.

Harnessing the water use efficiency measures

The impact of implemented water use efficiency measures is based largely on the regularity of the activities. As the stocktaking exercise shows, different factors must work together to ensure the efficient operation of the irrigation system. Some of these are beyond farmers' control, but the close collaboration with extension services and the management of the scheme can help improving the overall performance of the irrigation scheme. Other operations, on the contrary, can be directly implemented and followed by any practitioners.

Water use efficiency measures are commonly categorized into two major groups: Operation and Maintenance of the irrigation system and Water monitoring. The Guide gives a generic description of the measures under these two groups, and then it presents their implementation in local contexts.

Operation and Maintenance (O&M) for open-canal systems

There are some common problems which frequently occur in and around hydraulic structures. Most of them are related to the lack of proper O&M. Such issues as outdated parts, deterioration of the structures by extreme climatic event, missing movable parts or vandalism are difficult to prevent, but their negative effects can be minimized by carrying out proper maintenance. Reasonably, little can be done if the original design is wrong, and the scheme management should be informed accordingly on the necessary troubleshooting. Nevertheless, the majority of problems can be solved by the users themselves through a proper O&M of their irrigation systems. This section presents these problems and provides practical solutions to resolve them.

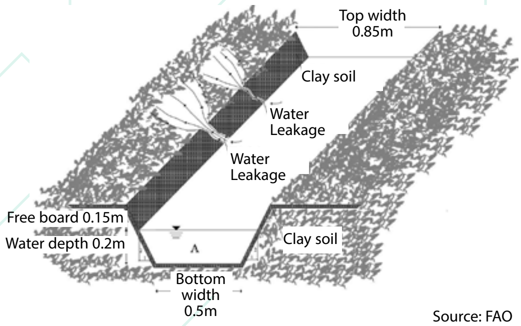
Leakage

Water use efficiency measure: Fixing leakages of the irrigation system

Leakages are one of the most common problems encountered in irrigation systems. Particularly, if the system is gravity-fed, the upstream part is considerably higher than the largest downstream part, and when there is a lack of control, the flow can result in damaging. Once leakage occurs, water easily enlarges its path by washing out the soil around. Leaking can appear around the intake/offtake structures, along the canal, or through cracks at the bottom or along the banks of the canal. Cracks are often not visible, but the soils become saturated around the canal, and waterlogging occurs. The hairlines and actively leaking cracks can be repaired locally with waterproof materials – such as pitch, grout injection, crystalline solutions, which does not require engineering work.

If the water source has a significantly higher level than the conveyance structures – the canals – water can flow over the intake structure and cause serious damages. The situation is the same at each offtake structures which supplies water from a higher level to a lower level canal (e.g. from main canal to secondary canal, from secondary canal to tertiary canal). If the leakage is consistent, it ends up as waterlogging. In order to avoid leakages along the structure, the offtakes and their grounding should be reinforced to resist the maximum load.

Figure 17: Typical leakage on the canal banks



Source: FAO

At tertiary canal level, the most common source of leakage is the overtopping around the intake gate and distribution boxes. The two major types of intake gates are: the controlled level intake and the open-level intake. The gates are often manual, and the distribution boxes are the only structures that control water level. If the intake gate is undersized, or the discharge is higher than the – required – design discharge, the structure is hit by overload. Since the structures are grounded and fixed, the design capacity cannot be changed. Therefore, farmers are recommended to keep the flow rate under the maximum capacity to protect their structures.

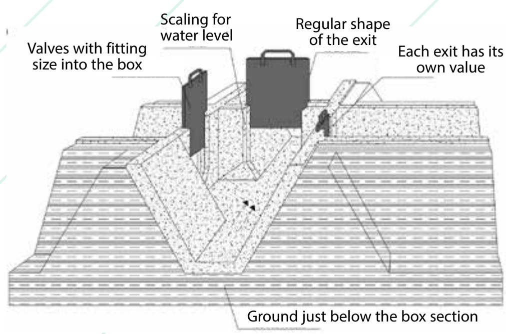
There is a vast number of engineering solutions to avoid leakages through construction or re-construction such as bank re-building or emergency outlet. However, these options require careful planning since they modify the original design. In such case, the management should be consulted and involved into the planning, implementation or rehabilitation work.

Seepage

Water use efficiency measure: Preventing seepage

Water seepage is a typical type of water loss in unlined/earthen canals. Water seeping through canal banks and bottoms results in a significant amount of water loss. In addition, it leads to oversaturated soils around the hydraulic structures. Seepage from canals is hard to control because water reaches deep layers without leaving traces. Unless water discharge is monitored along the canal, water loss can be only roughly estimated. Permeability of the canals depends on the soil type; in this respect, canals constructed from clay will have less seepage loss than the sandy soils. Seeping varies from very slow to very rapid due to different permeability of different soil textures. Table 4 presents the seeping depth per hours in different soils.

Figure 18: Distribution box and its regular use



Source: FAO

If seepage is significant, canal banks and bottoms should be reinforced. Lining canals with hard surface lining can be carried out to eliminate seepage, but it is often too expensive and makes irrigation system design inflexible. Reinforcing permeability of canal banks by compacting the soil, on the other side, is an inexpensive option for reducing seepage. The so-called core compaction reduces permeability and erosion, and improves load capacity of the bank. After excavating a trench in the canal bank (min 0.5*water depth and 20 cm below the original elevation), the core should be replaced while compacting more stable soil (such as clay).

Table 4: Permeability for the different soil types (FAO: Inland Aquaculture Engineering, 1984)

Soil type	Permeability (cm/hour)
Sand	5.0
Sand loam	2.5
Loam	1.3
Clay loam	0.8
Silty clay	0.25
Clay	0.05

Erosion

Water use efficiency measure: Preventing erosion

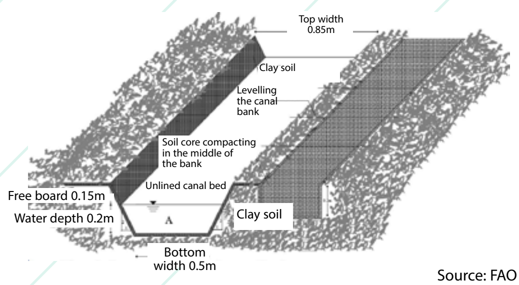
Unlined canals are often exposed to erosion, a natural process that can be caused by many reasons such as climatic event, changing soil texture, gullies and trenches, etc. Moreover, high discharge has damaging effect on canal banks and if the banks are not reinforced regularly, water can flush the structure away. Even small erosion can modify canal section and profile, thus, decreasing the canal performance.

Canal bank erosion can be stopped at its source and some examples can help understanding how maintenance can prevent adverse effects:

- if the erosion is due to frequent climatic event, canal banks should be reinforced by lining.
- if the erosion is due to gullies, gully-plugin, fencing, contour trenches or ditches should be applied.
- if the erosion is due to soil texture, canal banks should be reinforced by lining, core compacting or fencing.

Rainfall and wind are the most common climatic events which lead to bank erosion. If the canal is not lined and the soil is not compacted, the bed can be washed away. If the area is characterized by heavy rainfall or storm water runoff, hard surface lining with reinforced grounding is desirable. Otherwise, vegetation cover can provide protection, plant roots can hold the soil according to the root depth.

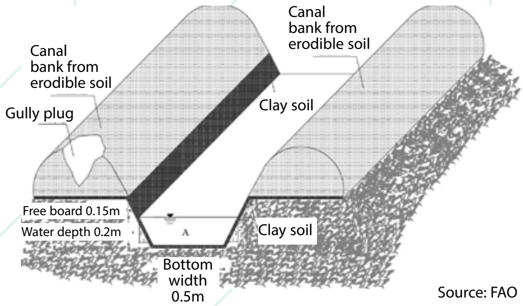
Figure 19: Core compacting of the canal bank



Source: FAO

Erosion gullies which are deeper than a foot can be repaired with simple filling and compacting. If the canal banks are eroded deeper than a foot, the erosion gullies need to be excavated, backfilled and compacted. The excavation must follow 1H:1V side slopes and the re-filling requires additional materials (e.g. clay, gravel or cobble) to repair the erosion feature.

Figure 20: Gully plug in the eroded canal bank



Source: FAO

Erosion will more likely occur if the soil of the canal bank has fine structure. Beyond the climatic event, fine soils are not sufficient for water conveyance, unless they are treated with compacting, reinforcing or lining.

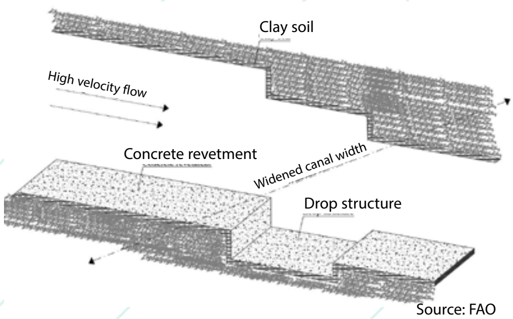
Uncontrolled flow

Water use efficiency measure: Fixed controlling structures

Uncontrolled flow, such as high velocity or any unexpected runoff can destroy the canal and flush away the hydraulic structures. Controlling structures have more functions amongst which the controlling of applied water amount and the protection of hydraulic structures are the most important. Fixed structures are more likely applied for the latter one. Uncontrolled flow can destroy the hydraulic structures, erode the canal bed and banks, and wash away the soil.

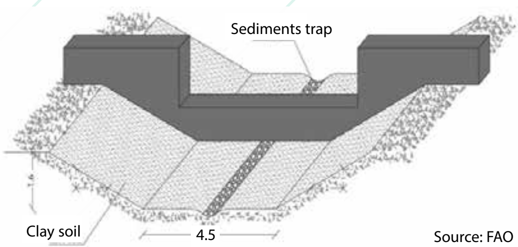
The bed is particularly exposed to erosion if canal design does not respect the average velocity of the flow. The high velocity damages the conveyance structures and also the hydraulic structures if they are not protected. In order to control the flow, single or multiple drop structures can be applied to reduce velocity by negotiating with the terrain sloping faster than the slope of the canal. There are many types of drop structures such as baffled chute drops, vertical riprap drops, vertical hard basin drops, sloping concrete drops and low flow check structures. The selection has several criteria: surface flow hydraulic performance, foundation and seepage, economic consideration and construction capacity. From

Figure 21: Drop structure for flow control



Source: FAO

Figure 22: Installed weir for flow control combined with sediment trap



Source: FAO

all, flow hydraulic performance is the most important criterion, which determines the design of the drop structures. The major design elements include the drop height, critical depth, brink depth, toe depth, pool water depth and length of the drop. If the dimensions are not properly designed, the drop structures can cause adverse effect in the flow. Therefore, drop structures are recommended at higher level canals such as main and secondary canals in small-scale schemes.

Another commonly used type of fixed structures to stabilize the flow is the constructed weirs. Apart from their function of measuring discharge, weirs are also deployed as flow control structures or emergency spillway devices. There are many types of weirs such as sharp-crested, broad-crested, triangular, or other intermediate sections with different head-discharge characteristics.

Siltation, sedimentation and debris

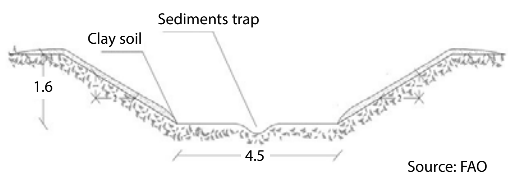
Water use efficiency measure: Sediment removal

There are many sources for siltation, sediment or debris along canals. The first major source is located where water is withdrawn. If the irrigation scheme is not equipped with trapping or filtering structures at the entry stretches, water transports silt and sediment, which can damage the intake structure, deposit on the canal banks and on bottoms, thus, decreasing the system performance. The canal can be also subject to debris flow deposition along the way. The siltation, sedimentation and debris deposits decrease the system performance and also damage the structures.

Cleaning, de-silting, removal of deposits is the first step of routine maintenance. Regular cleaning by excavation helps maintaining canal performance and prevents deterioration of the system. Cleaning does not require expensive equipment and can be done manually in small canals (e.g. by digging hoe). However, cleaning should not modify the original system design. An earthen canal should, thus, be cleaned and sand deposit should be removed while respecting the original dimensions of the canal.

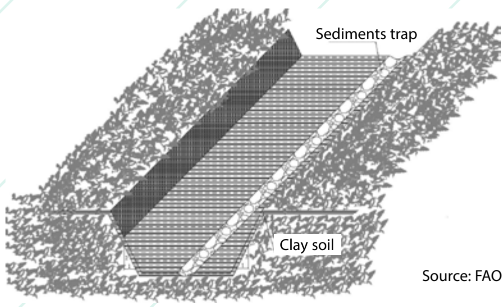
The sediment load of water highly depends on water source. If water comes from earthen ponds or dams, for example, it can carry larger load of sediment than a canal sourcing water from a high-velocity river. Even if the majority of irrigation systems are not equipped with sediment filters at the intake gate, farmers can deploy techniques to deposit the sediment in the canal before applying water on their fields. Small sediment basins on the canal bed help depositing the undesired sediment. If the tertiary canals are unlined, digging a small hole

Figure 23: Small basin as sediment trap in unlined canal



Source: FAO

Figure 24: Sediment trap in unlined canal



Source: FAO

on the bottom captures the sediment without modifying the flow. This technique is recommended for low velocity flows in earthen canals where famers can easily re-load the filled basin. When sediment has accumulated to the half of the design volume of the basin, the re-load is necessary to avoid the erosion.

Deteriorating canal profile

Water use efficiency measure: Canal profiling

Unlined canals often lose their original dimensions and profile over time due to erosion, siltation, high velocity flow without associated steep slope or uncontrolled runoff, and they become deteriorated. The changing profile along the canal has several consequences such as unequal water distribution, waterlogging, difficult distribution on the field, etc. In addition, a too wide and deepened canal profile requires high water level to lift water from the canals to the farms.

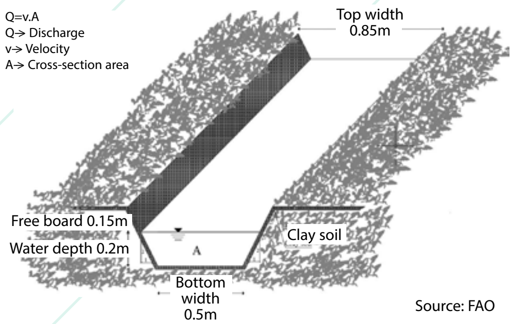
Canal profile should follow the dimensions of the original design. If the canals are wide and deep, the design should be fixed by filling and reinforcing the banks. Then, the canal profile should be protected by several other water use efficiency measures. While re-shaping tertiary canals, there are some recommendations to ensure their long-durability and high performance.

When considering lining, there are numerous criteria to meet. Lining is often expensive and it creates an inflexible design; therefore, farmers have to decide on the feasibility of the investment in lining their canals. If water supply is very limited and seepage loss is high, lining can be an option to decrease water use. Additionally, if the soils are too instable to keep the canal profile, lining is more reasonable than re-shaping canal frequently. There are many options for lining but the most applied methods are: bricks, concrete, rubber or polythene. Once the lining is ready and the initial investment is re-paid, the maintenance is easier.

The profiling/shaping of the canal should follow the original design. The majority of tertiary canals have rectangular or trapezoidal shape, depending mainly on the soil type, the design discharge, the size of the irrigated area, and the lengths of the canal.

The rectangular shape is recommended for canals lined with strong and stable materials such as concrete or brick; while trapezoidal shape can be widely applied. If the canal is not lined, the trapezoidal shape is recommended depending on the soil type. Loose, sandy soils are more exposed to erosion and deterioration; therefore, the angle of the side slope should be less steep. The steeper side slope requires more stable soils and materials. Table 5 includes the recommended standard values of the side slopes.

Figure 25: Typical canal section of small, unlined canals



Source: FAO

High velocity not associated with proportionally steep slope is one of the most common reason of deteriorating canals. A velocity rate higher than the design capacity destroys the soil texture and stability. When planning the flow rate in unlined canals, the standard maximum permissible average velocities should be taken in account.

Table 6: Maximum permissible average velocity in unlined canals (FAO Training Series 8 - Simple methods for aquaculture, 1998)

Type of soil	Maximum permissible average velocity (m/s)
Soft clay or very fine clay	0.2
Very fine or very light pure sand	0.3
Very light loose sand or silt	0.4
Coarse sand or slight sandy soil	0.5
Average sandy soil and good loam	0.7
Sandy loam, small gravel	0.8
Average loam or alluvial soil	0.9
Firm loam, clay loam	1.0
Firm gravel or clay	1.1
Stiff clay soil, ordinary gravel soil, or clay and gravel	1.4
Broken stone and clay	1.5
Corse gravel, cobbles, shale	1.8
Conglomerates, cemented gravel, soft slate	2.0
Soft rock, rocks in layers, tough hardpan	2.4
Hard rock	4.0

Table 5: Recommended side slopes for rectangular-shaped canals in different soil types (FAO: Training Series 8 – Simple methods for aquaculture, 1998)

Type of soil or lining material	Side slopes not steeper than	
Light sand, wet clay	3:1	18 °20′
Loose earth, silt, silty sand and sandy loam	2:1	26 °30′
Ordinary earth, soft clay, loam, gravelly loam, clay loam, gravel	1.5:1	33 °40′
Stiff earth or clay	1:1	45 °
Tough hardpan, alluvial soil, firm gravel, hard compact earth	0.5:1	63 °30′
Stone lining, cast-in-place concrete, cement blocks	1:1	45 °
Buried plastic membrane	2.5:1	22 °30′

Table 7 presents some of the maximum average velocity values in lined canals.

Table 7: Maximum permissible average velocity in lined canals (FAO Training Series 8 - Simple methods for aquaculture, 1998)

Type of lining	Maximum permissible average velocity (m/s)
Cast-in-place cement concrete	2.5
Precast cement concrete	2.0
Stones	1.6-1.8
Cement blocks	1.6
Bricks	1.4-1.6
Buried plastic membrane	0.6-0.9

Irrigated land size is the most relevant criteria in the designing of the canal system. Since the velocity is constrained by the type of the soils, the size of the canals should counterbalance it to reach the required discharge1. Evidently, smaller farms require lower discharge. Table 8 provides an example of how the dimensions of the trapezoidal earthen canal are differentiated according to the irrigated land size.

Table 8: Trapezoidal canal dimensions according to the irrigated land size (source: FAO Training Manual 8: Simple methods for aquaculture, 1998)

Dimensions	Land < 10 ha, requiring Q < 20 l/s	Lands > 10 ha, Requiring 20 l/s<Q<50 l/s
Bottom width (m)	0.25	0.5
Water depth (m)	0.15-0.20	0.15-0.25
Free board (m)	0.10-0.20	0.20-0.30
Side slope (%)	2:1	2:1
Top width (m)	0.80-1.50	1.50-2.50

Several other factors affect the profile of tertiary canals, such as extreme climatic events, the position of intakes and offtakes, sediment transport or levelling and related altitude. The change is often a long and invisible process; however, maintaining the original shape of the canal is more cost-efficient than an intervention to re-shape the canal.

Weeds, bushes and undesired vegetation

Water use efficiency measure: Removal of undesired vegetation

Vegetation on canal banks are useful to help maintaining the canal shape, stabilize the soil, thus to prevent erosion. The use of vegetation cover is recommended in canal banks which are exposed to heavy rain or wind. However, the vegetation must be controlled and undesired vegetation should be removed regularly.

Vegetation and aquatic plants can grow inside and around the structures, and negatively affect water use efficiency in both cases. Indeed, while the vegetation around the canals evaporates a massive amount of water, the aquatic plants decrease the performance of the canal by blocking the flow. Three major types of aquatic plants can be distinguished: emergent, submerged and floating plants. Aquatic weeds can be controlled by mowing, dredging or harrowing.

Weeding, bushing and removal of aquatic plants are regular maintenance works during the irrigation season that can be done manually. Although this work does not necessary require equipment, it must be carried out frequently since these plants are usually resistant and spread very fast. The main types of maintenance are the vegetation control with hand tools, vegetation control with mechanical machinery, chemical maintenance and biological maintenance. Certified and registered herbicide use is highly recommended to kill the roots of these plants, thus minimizing the required manual work during the season.

[1] Discharge (Q) is calculated from the velocity (v) and the area of the canal section (A), Q=vA (discussed in the next chapter)

Damaged hydraulic structures

Water use efficiency measure: Maintenance of hydraulic structures

Even gravity-fed systems with simple hydraulic structures such as manual sluice gates, weirs, gated cross-regulators, are exposed to deterioration, vandalism and any other damage. Additionally, moveable items require careful maintenance, and if the missing items are not properly replaced, the functionality of the structure reduces. Depending on the material, rot and rust can adversely affect the efficiency.

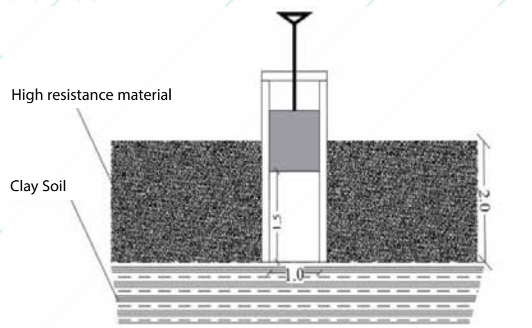
Another concern is the proper grounding of the structures. If the grounding is not solid enough, the structures can easily break while destroying the other parts of the structures. Grounding and fixing always require careful maintenance and regular inspections.

Maintaining the original design of hydraulic structures is essential, as well as the installation and operation:

- Stable grounding ensures the durability of the structure. Both the environment around the structure and the soil should be reinforced in the case of persisting load.
- Hydraulic structures cannot be converted or used for non-intended scopes, more functionality cannot be added. Only while maintaining the hydraulic structure, the original design and manufacturers' instructions provide the intended use.
- Depending on the material, the hydraulic structure should be protected by preparation work (polishing, painting, conditioning, etc.).
- Lubrication of moveable items, more than their replacement, eases the operation, extends the lifespan and preserves the structure.
- Regular inspections are recommended for each hydraulic structure. If the flow is blocked, the structures are to place out of order until the problem is revealed and fixed.
- Durability and resistance of the hydraulic structures highly depend on the load. If the water flow is beyond the design capacity, the structure can be damaged. Keeping the flow below the maximum capacity helps extending the lifespan of structures.

Since a large number of hydraulic equipment are employed, manufacturer instructions should be followed in every case. Flow regulators, control equipment and other structures that modify the original design and affect the flow should be manufactured and installed by engineers.

Figure 26: Sluice gates in concrete chamber



Source: FAO

Enhancing water use efficiency through O&M measures: Country cases

Putting the measures into practice requires diagnostic analysis of the scheme and careful planning. The pilot schemes were appraised in order to define the best-fitting combinations of these measures. The appraisal involved the following steps to prepare improvement practices:

- Collection of climatic and hydrological, agronomic and management data and compilation of comprehensively dataset.
- Identification of the inefficiencies of the system and established baseline assessment.
- Performance diagnosis of the irrigation system.

Each of the measures were trialled in any of the schemes to identify their applicability and their effect. The country cases provide insight into their effective implementation and establish good practice for O&M in the schemes.

Water use efficiency measures concerning O&M in Ben Nafa Kacha, Burkina Faso

In Ben Nafa Kacha Scheme, the main and secondary canals are concrete-lined with trapezoidal shapes. The main canal is around 1 088 m long and 3.2 m wide with around 0.5 to -0.8 percent average slope. The secondary canals are vertical to the main canal, and water is off-taken through "modules a masques". The average length of the secondary canals is 1 080 m, the supplied zones are uniform, and each secondary canal irrigates 60 ha.

The system is supplied by three large capacity pumps with 300 l/s capacity each. Water is withdrawn from the river through Archimedes screws into the main canal. The design capacity of the main canal allows the withdrawal and temporal storage of a large amount of water. The length, width and depth of the canal enables water storing. The main canal has major water losses through cracks in the concrete lining and the joints that are not tightly sealed. Secondary canals were full of weed and silt, which caused overtopping. The erosion of the soil surrounding these canals undermined the stability of the banks. The secondary and tertiary canals have "module à masques" to off-take water. The tertiary canals are unlined, a heavily deteriorated distribution box conveys water into the field ditches. The excess water is conveyed into drains and then back to the River.

The cost of water pumping is transmitted into the water fees, therefore, farmers are continuously exposed to the fluctuating energy prices. Improving water use efficiency through minimizing water loss and optimizing applied water is crucial to ensure the feasibility of production. Addressing the paddy rice production in multi-cropping system is particularly important since rice - as staple crop - helps increasing the household food security. However, inserting basin irrigation into small-scale multi-cropping system remains a challenge in terms of irrigation management.

Concerning the necessary O&M works in the irrigation scheme, this section represents the recommended combination of water use efficiency measures to improve irrigation performance.

Water use efficiency measure: canal erosion and overtopping

The fine soil structure without compaction caused canal erosion around the banks; the banks were further eroded by active gullies along the main, secondary and tertiary canal. The damage could have been exacerbated by breaking through the canal banks or flushing away the soil around the structure.

Whenever canal erosion occurs, reinforcing the banks by compacting and supporting the bank vertically is recommended. The gully was plugged by compacted soil, and the canal section was reinforced by concrete filling. At main and secondary canals, the concrete is massive enough to carry the water load, but the soil compression of the earthen canals' banks was essential to preserve the canal shapes and prevent the gully.

Figure 27: Eroded canal bank in the secondary canal

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Figure 28: Repaired canal bank with concrete filling and compacted soil

©FAO/Abdelouahid Fouial

Water use efficiency measure: removal of undesired vegetation

The bush along the lined canal significantly reduced canal performance by blocking the water flow. The roots enlarged the cracks on the canal banks, and evaporate a large amount of water. The vegetation made the accessibility (inspection road) and the related maintenance work difficult. Moreover, the weeds are spreading fast around the farms reducing the harvested yield.

The manual removal of bushes is recommended to clean the sites. The weeds can be removed around and in the farms manually while avoiding the uprooting of the crops. Locally available and certified herbicide should be applied in the farms and manual weeding should be carried-out around the water conveyance structures at main and secondary levels – including the drains. The unlined tertiary canals consists of fine soils, so vegetation control should apply grassing to stabilize the soil around the canals.

Figure 29: Vegetation breaking through the hairlines in the canal bed

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Figure 30: Lack of vegetation control around the tertiary canal banks

©FAO/Eva Pek

Figure 31: Complete vegetation removal around the lined canals

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Figure 32: Enlarging cracks in the secondary canal

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Water use efficiency measure: fixing the cracks on lined canals

Lined canals are constructed from concrete sections. The joints between the sections were particularly vulnerable since the sealing is not solid, cracks occurred on canal banks. Over time, the cracks enlarged and either the water seeps to deep soil layers or the soil becomes saturated. Repairing secondary canals is particularly important since farms are around the secondary canals and the soil saturation around the leakage can lead to partial failing of production.

Persistent materials are available to condition the cracks and reinforce the sealing. Pitch is an optimal option to fill the cracks in the concrete due to its thermal expansion capacity and easy-shaping. Since the conditioning requires empty and dry canal, the works should be carried out before the irrigation season, and the joints should be inspected regularly.

Water use efficiency measure: maintain the hydraulic structures – distribution boxes

Due to the high water discharge, the tertiary canals with small design capacity lost their profile and they became wide. The distribution boxes are eroded due to their fragile grounding, and the structures are completely broken. Since the current boxes need complete replacement, thus, requiring a high investment cost, their function should be replaced by allowing the control of water in an alternative way.

Each distribution box is equipped with "vannettes" to control discharge. The farmers distribute water among the ditches. However, large water supply causes waterlogging, therefore, the introduction of a revised irrigation schedule is needed to avoid deterioration while reinforcing canal banks.

Figure 33: Conditioning the cracks with pitch

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Figure 34: Broken distribution boxes and widened canal section at tertiary level

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Water use efficiency measure: profiling the tertiary canals and levelling

The tertiary canals are unlined earthen canals. Due to the lack of maintenance and reinforcement, the canals became wide and deep. The sandy-loam soil is not stable enough to keep the canal profile in long term. Moreover, the applied discharge is higher than the design discharge, thus making the canal bed more erodible. The irrigation of paddy rice is a particular constraint to follow the rotated irrigation turns. The high evaporation of the basins forces farmers to irrigate from the secondary canals by syphons, thus, reducing the discharge at the downstream part of the secondary canals.

The canal shape was re-defined considering the size of the farms and the required nominal discharge, the average velocity, the soil type, and the length of the canal:

- The average zone size irrigated by one tertiary canal is 10 ha, and one farm has a size of 1 ha. The tertiary canal should be able to convey 30 l/s nominal and 70 l/s maximum discharge.

- The average velocity in the tertiary canals can be calculated from the "modules a masques". The recent design is made for 0.3-0.45 m/s. The current value is the maximum permissible average velocity of this type of sandy soil. Diverting flow with higher velocity into the tertiary canals might lead to deterioration.

Figure 35: Syphoning from the secondary canal into the rice basins

©FAO/Eva Pek

- The sandy soil does not provide a stable embankment; therefore, the slope should not be too steep. The design of the tertiary canal should follow the standard values presented in the previous section. The recommended side slope is around 25 – 45° according to the standard values.

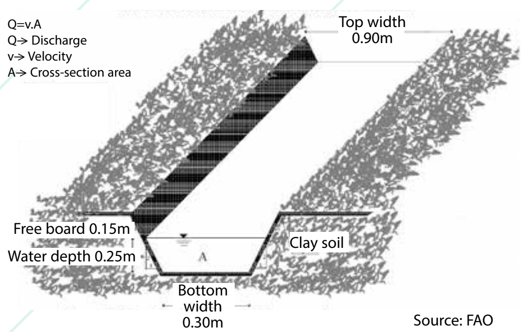
Finally, based on the spacing between the farms and the lateral offtakes from the secondary canals, the recommended dimensions of the trapezoid canals are: 0.9 m top width, 0.25 m depth, and 0.3 bottom width.

Also, regular shape must be kept along the irrigation canal. Since the tertiary canals are long, machinery work is recommended to create the right profile. Due to the shallow and irregular slope of the main canal, the levelling should follow the main canal.

Inserting paddy rice irrigation by basins creates difficult situation in multi-cropping systems which are primary irrigated by furrows. Basin irrigation enables the submerged growing in water. It provides the best conditions for paddy rice which requires continuous water cover. But, the benefits of basin irrigation depend on many design parameters, which should be followed from the water withdrawal to the on-farm water application. The flatter is the land, the easier is to design a well-performing structure. Since the area of the Scheme is plain, only minor levelling is required. The Scheme conditions with the shallow slope are sufficient to construct rice basins.

The farmers do not practice land restoration due to the continuous pressure of food availability. Set-aside is not present in the Scheme and the soil fertility is not addressed by the agricultural practices. Apart from the agronomic measures, the declining soil fertility

Figure 36: Re-designed tertiary canal profile with appropriate dimensions



Source: FAO

and thinning topsoil can be counterbalanced through implementing a careful design. Significant amount of fertile topsoil can be saved from excavation if the levelling is and rather water level is varied by the equipped distribution boxes. In order to carry out the water level altering in small-scale irrigation, the dimensions of the basins should be reduced to optimal size. The current average slope of the Scheme is 0.2-0.4 percent. According to the recommendation of FAO Irrigation Water Management, Training Manual 5, the maximum width of the basins should not exceed the 55 m.

Table 9: Recommended width of the basin per average slope value (source: FAO - Irrigation Water Management: Irrigation Method, Training Manual 5, 1990)

Slope %	Average maximum width(m)	Range of maximum width (m)
0.2	45	33–55
0.3	37	30–45
0.4	32	25–40
0.5	28	20–35
0.6	25	20–30
0.8	22	15–30
1.0	20	15–25
1.2	17	10–20
1.5	13	10–20
2.0	10	5–15
3.0	7	5–10
4.0	5	3–8

Other parameters determining the optimal basin size are the discharge entering the basin and the soil type. The less discharge flows into the basin, the smaller size is recommended in order to effectively fill up the basin.

Table 10: Recommended basin size according to the discharge (FAO - Irrigation Water Management: Irrigation Method, Training Manual 5, 1990)

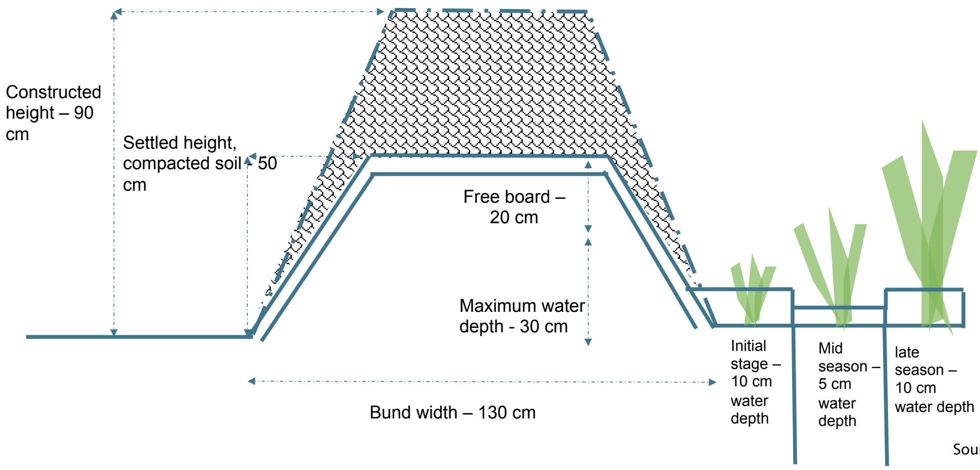
Discharge (l/s)	Sand (m^2)	Sandy loam (m^2)	Clay loam (m^2)	Clay (m^2)
5	35	100	200	350
10	65	200	400	650
15	100	300	600	1000
30	200	600	1200	2000
60	400	1200	2400	4000
90	600	1800	3600	6000

Furthermore, many other factors influence the recommended size of the basins, such as:

- Production method: if the production is fully manual, the smaller size helps farmers to carry-out works in their lands.
- Required depth of water: for small required level, the basin should be also small. The recommended water depth in initial and late season should not exceed 12 cm, and 5 cm in the development stage. Therefore, smaller basin size is rather recommended in the Scheme.

Compacted contour bunds surrounding the basins are helpful to the carry the water load. Furthermore, the permanent bunds help preserve the shape of the basin and enable the altering of water level. The bunds should not be less than 40 cm when the soil is settled (compacted). Trapezoidal shape of bunds is recommended in sandy and sandy-loam soil with 130-160 cm width.

Figure 37: Contour bund for paddy rice with the recommended dimensions and water level



Source: FAO

The levelling of the basin is essential to distribute water evenly throughout the farm. The flat land in Ben Nafa Kacha does not require major earth work and earth removal, but the current basin bottoms are often muded and irregular. The levelling could be easily improved by fixing the basin boundaries with countour line and setting out markers.

Currently, the paddy rice farms are often over-sized (2 500 m^2), the contour-bunds are damaged by erosion and the water level is not controlled at farm level. Splitting the lands into smaller size farms and filling the plots from different directions could help improve the efficieny of basin irrigation.

Water use efficiency measure: maintain the hydraulic structures – module a masques

"Modules à masques" are free surface water intake structures used to ensure and control constant flow. The discharge can be adjusted by fully opening or closing small gates of different widths. Once the gates are opened and locked, the discharge remains constant even if the upstream and downstream water levels vary. "Modules à masques" come in the form of mono-block metal assemblies that are sealed to the side of irrigation canals. There are 36 "modules a masques" in the Scheme, 6 along the main canal (1 of the type XX290 and 5 of the type XX2150) and 30 of the type X130 along the secondary canals. Farmers can easily control the discharge delivered to their farms.

Figure 38: Broken "modules a masques" between the secondary and tertiary canals

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Figure 39: Repaired and reinforced "modules a masques" with concrete chambers

However, the "modules a masques" require careful maintenance. Both the moveable items and the grounding are sensitive; and the intended use should be followed. Between the secondary and tertiary canals, they are installed with concrete grounding. Often, overtopping occurs due to the large discharge which exceeds the design discharge of the canals and the "module a masques".

The application of lubricants and painting is recommended to preserve the condition of the structures. Even if the grounding is concrete, the canal banks are eroded beyond the structure. The banks should be compacted and enforced to protect the structure. Also, the controlling of flow supply is necessary not to exceed the maximum discharge. Otherwise the structures can deteriorate from the overtopping.

Water use efficiency measures concerning O&M in Haouz Sector 3 – Morocco

In Haouz Sector 3, water is sourced from the Barrage Hassan I. The area is characterized by plain lands, and the elevation is not sufficient to convey water by gravity. Therefore, the irrigation system design is based on mounted open canals. From the main canal to the tertiary canals, water runs through mounted canals, and the offtake is through "module a masques". Water then is dropped from the tertiary canals into earthen quaternary canals.

The area is hit by severe water scarcity. In 2017, irrigation prohibition came into force when Morocco experienced one of its most devastating drought events. The frequency and the duration of the droughts have increased rapidly and the country has to face the exacerbating climatic events. As such, farmers are forced to adopt new irrigation practices to enable more production from less water resources.

This section represents recommended combinations of water use efficiency measures to improve irrigation performance that concern necessary O&M works.

Water use efficiency measure: fixing the cracks and joints conveyance structures

The main, secondary and tertiary canals in Haouz Sector 3 are mounted to ensure sufficient slope for water conveyance. Although, canal banks are not exposed to erosion, the weakening joints have large leaks, thus the water loss is significant. Wherever the sealing is not solid enough, leakage can occur. Although the conveyance efficiency of this type of canal is high, the cracks and broken joints can lead to complete damage.

After inspection, the joints and the cracks are fixed and enforced by fast-setting materials.

Water use efficiency measure: maintain the hydraulic structures – module a masques

"Modules à masques" are free surface water intake structures used to ensure and control constant flow. The discharge can be adjusted by fully opening or closing small gates of different widths. "Modules à masques" are manufactured according to 4 standardized types of different dimensions, characterized by the nominal discharge per unit of width: Series X, XX, L and C.

The 4 types have different dimensions with different design capacity. The nominal discharge of these types are:

- Série X: 10 l/s/dm= 1 l/s/cm
- Série XX: 20 l/s/dm= 2 l/s/cm
- Série L: 50 l/s/dm= 5 l/s/cm
- Série C: 100 l/s/dm= 10 l/s/cm

Figure 40: Mounted conveyance structure with active leaking

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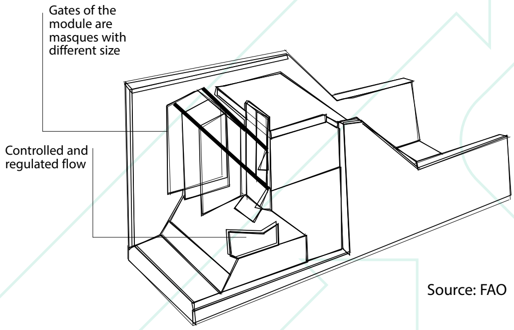
Figure 41: Modules a masques offtakes for flow control



Source: FAO

The "module a masque" is designed to control flow by the opening of the "vannettes" separately. Each "vannette" can be opened and closed independently from the others. This flexibility enables the structure to regulate and also control the flow. The discharge capacity is:

- 5 l/s per vannette for Série X (vannettes 5, 10, 15 and 30 l/s),
- 10 l/s per vannette for Série XX (vannettes 10, 20, 30, 60 and 90 l/s),
- 50 l/s per vannette for Série L (vannettes 50, 100, 200 and 400 l/s),
- 100 l/s per vannette for Série C (vannettes 100, 200, 400, 600 and 1000 l/s).

The "module a masques" are designed to ensure stable and constant flow. Nevertheless, the structures are not functional in the scheme. There is no water conveyance structure between the mounted tertiary canal and the ground-level quaternary canals. Moreover, the high discharge floods the lands around the outlets.

The design discharge of the "vannettes" enables the water monitoring and the setting-up of hydrological water balance along the conveyance system. The difference between water measured in the tertiary canals and applied water amount presents the water loss during off-take. Since the area is characterized by water scarcity, the efficiency of water distribution should be improved.

The "modules a masques" require regular painting to avoid rusting. The lifespan of the structures can be extended if the material is well-conditioned and the moveable items are treated with lubricants. Also, if the distribution box is mounted or their walls are heightened, the water offtake into the quaternary canals is more efficient. However, the current design allows to improve the water use efficiency through controlling the discharge. The discharge should be reduced to minimize the losses while water is dropping.

Water use efficiency measure: removal of undesired vegetation

Undesired vegetation covered the hydraulic structures and their environment at tertiary and quaternary levels. Both the canal and their banks were covered by weeds. Common reed surrounding the canals and the agricultural lands is one of the major concerns. As invasive plant, it can substantially modify the landscape, and the reed cover increases the desiccation, thus, decreasing soil fertility. Since the area is hit by water scarcity, water should be utilized only by the productive plants, and weeds should be removed.

The canal profiling included the demolishing and cleaning of the sites from vegetation. Due to the dense root matrix of the reed, mechanical weeding was carried out. Since the area is shallow, the banks are not exposed to erosion by high velocity or rainfall, complete vegetation removal was done.

Figure 42: Modules a masques dropping water into ditches

Figure 43: Measurement of flow velocity for flow control

Figure 44: Weed spreads around the hydraulic structures and cover the ditches

Water use efficiency measure: profiling the tertiary canals

The quaternary canals are unlined, small earthen canals without profile, and covered by vegetation. They became shallow from the siltation deposit, while the canal entry is widened and eroded from the dropping water flow. The flat area does not have sufficient slope to convey water, therefore, lining is necessary at quaternary level to increase the conveyance efficiency.

Since water is scarce, the soil permeability is high, and it is exposed to significant water loss, the lining of the quaternary canals is recommended to increase their conveyance efficiency. The quaternary canals are long and wide and the water level depth is shallow due to the slope, therefore, the hard surface lining (concrete, brick, etc.) is economically infeasible. Compacting soil at the intake and applying Geomembrane address the concerns around the conveyance while providing a cost-efficient and flexible lining method in water scarce and flat area.

Figure 46: Water dropping from "modules a masques" into the distribution boxes

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Figure 45: Mechanical vegetation removal from the canals

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Figure 47: Geomembrane cover in the quaternary canals

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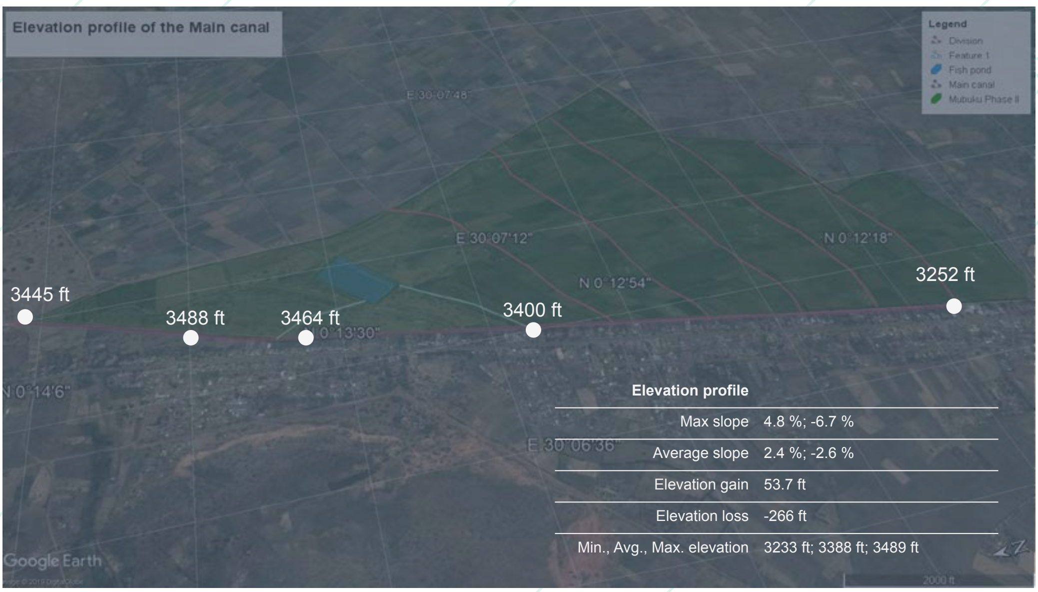
Water use efficiency measures concerning O&M in Mubuku – Uganda

Mubuku irrigation scheme in Kasese region was established under a governmental programme to create job in rural areas and improve national agricultural production. As Uganda has significant unexploited irrigation sources, improving the performance of irrigation schemes gives high potential for agriculture in the country. In addition, Mubuku irrigation scheme has favourable climatic conditions giving two agricultural seasons with sufficient amount of rainfall.

Mubuku is a gravity-fed system supplied by Sebwe River. Water is conveyed through open canals; Phase II has one main canal, five secondary canals (Divisions), and each secondary canal has five or six tertiary canals. The main and secondary canals are lined with concrete, and the tertiary canals are small-unlined canals distributing water into earthen quaternary canals. The distribution is through gated off-takes. The average slope of the scheme allows flow with high velocity. The average slope is 2.4 percent and – 2.6 percent, the overall elevation loss is 81 m. In order to negotiate with this high change in elevation, a few drop structures are deployed to slow down the velocity. However, the number of structures are not sufficient to control the flow and the high discharge often results in waterlogging in the most downstream farms. The design of the system is in lack of exit outlets, so the excess water is led through the most downstream farms into the drains. On other sides, the condition of the lined canals is sufficient, the canal banks are not eroded, and cracks are rare while the vegetation is removed adequately.

However, the final deliveries and hydraulic structures need more improvement to increase water use efficiency. The unlined canals are deteriorated, and the canal banks are not accessible due

Figure 48: Elevation profile of the Main canal in Mubuku scheme (edited from Google Earth)



Source: CIHEAM BARI, 2019

to undesired vegetation. The gates are broken and the distribution boxes are damaged by high discharge and overtopping. Even if the main and secondary canals are in good conditions, the overall water use efficiency in the scheme is undermined at tertiary and quaternary level.

This section represents recommended combinations of water use efficiency measures to improve irrigation performance that concern necessary O&M works.

Water use efficiency measure: controlling flow

The concrete main canal and Divisions are stable to convey the high discharge flow, but the earthen tertiary canals are damaged. The canal profiles are widening, and the banks and bottoms are eroded. The tertiary canals used to convey higher than the design discharge (around 60–90 l/s) with high velocity. The overall surface elevation from the intake gate to the tail of the canal is steep (-1.9 percent) and the significant altitude change starts at the first diversion point (before the diversion between the irrigated lands and fish pond), where the elevation drops by 4 %. Along the main canal, drop structures slow down the velocity, but the number of the structure is not sufficient to control and also tranquilize the flow. Consequently, the high velocity led to canal bottom erosion and irregular profile. The tertiary canals became often larger than the secondary canals, and the bottom is eroded thus making the water distribution difficult. Moreover, the sediment carried by the flow is deposited in the entry stretch of the tertiary and quaternary canals, thus blocking the flow coming from the distribution boxes.

Beyond its discharge measurement function, weirs are deployed to control the flow at main, secondary, and tertiary canal levels in one of the Divisions. The regulating weirs at tertiary level reduces the discharge and velocity, so downstream farms are not exposed to

Figure 49: Destroyed distribution box, widened and unshaped quaternary canals


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Figure 50: Sedimentation deposit in quaternary canals


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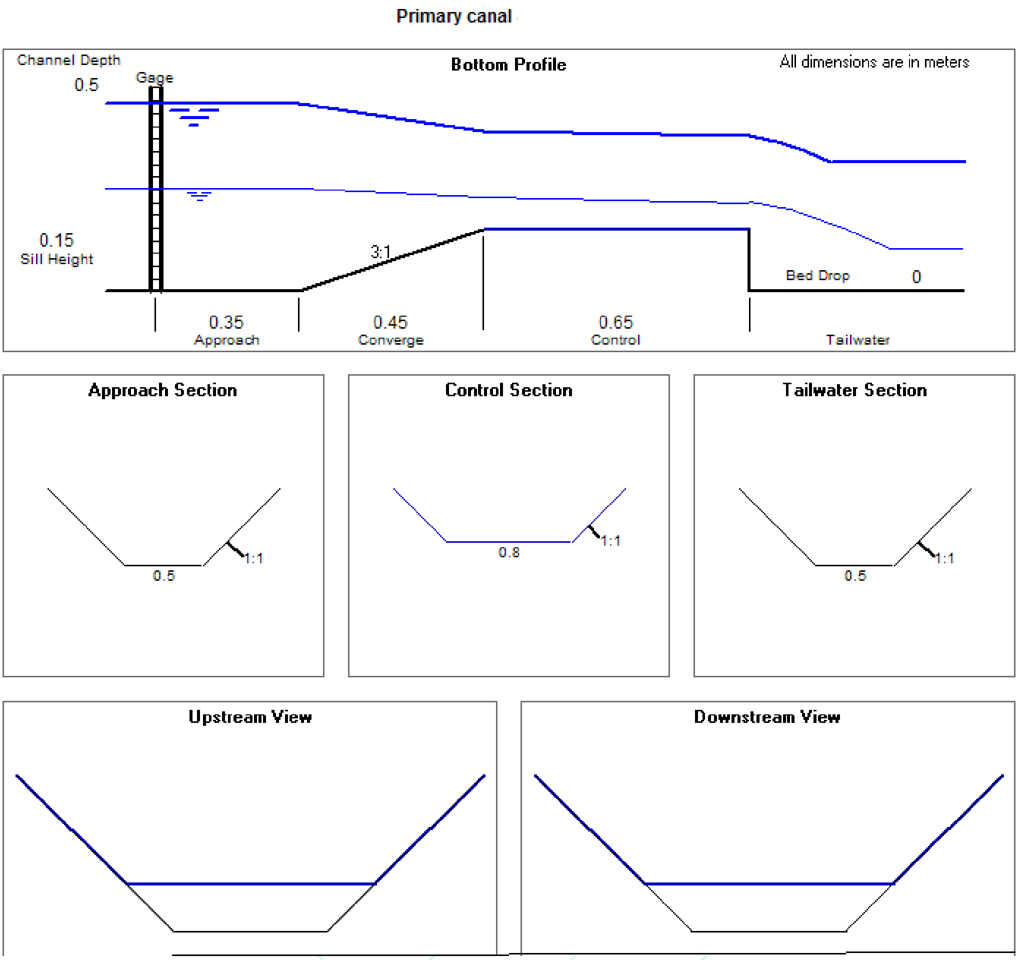
waterlogging. The broad-crested rectangular weirs are designed at different sizes according to the design discharge of the canals. The design criteria included the maximum and minimum flow rates, slope, and the free board. The canal sections are regular enough, thus, negotiation a robust relation between flow rate and water depth. Those conditions are suitable for using the Manning's equation in order to determine the depth.

Figure 51: Construction of the weirs in the Main canal

Figure 52: Design dimensions and sections of the weir in the Main canal (equivalent to Primary canal)



Source: FAO

The average discharge often exceeded 70 l/s due to the irrigation schedule, therefore, the unlined canals are exposed to high maximum discharges, thus, requiring more effective flow regulation. At tertiary canal level, the weirs are designed to small-scale and their main function is to control the water inlet and reduce the velocity before it reaches the quaternary canals. Due to the regulated flow, the distribution boxes are also protected from heavy load.

Figure 53: Weirs at tertiary canal level in Division 8

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Water use efficiency measure: hard surface lining and profiling at final delivery level

Apart from water controlling, the tertiary canals are damaged by the discharge over-load, the lack of maintenance, and heavy rainfall. The eroded canals lost their shape and they became wider than the secondary canals. The same deterioration applied to the quaternary canals. Since the quaternaries are excavated by the farmers without any instructions on the design dimensions, the farmers created often too wide and shallow ditches. Moreover, the carried sedimentation were dumped in the entry stretches, thus, elevating the bottom. Therefore, conveying water required high water level in the tertiary canals.

The eroding factors required hard surface lining at tertiary canal level in order to resist the load and the climatic events. This high velocity requires stable soil and shallow slope. Even if the soils are stable, but the slope of the canals are too steep, the lining of the first section of tertiary canals was implemented in order to evenly distribute water to the quaternary canals. The lined part stabilizes the flow while protecting the entry section of the canal.

Furthermore, the whole length of the tertiary and quaternary canals were profiled to enable the efficient distribution of water. The quaternaries were lined with compacted soil around, and the width were narrowed to adequate size to ensure efficient inlet from the distribution boxes. The bottoms were excavated and elevated to lower the required water level from tertiary level.

Figure 54: Construction of the tertiary canals with brick and concrete

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Figure 55: Reinforced and lined tertiary canals

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Figure 56: Quaternary canal before the construction

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Figure 57: Construction inspection before the lining of quaternary canal

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Figure 58: Lined quaternary canals with sufficient dimensions for water distribution

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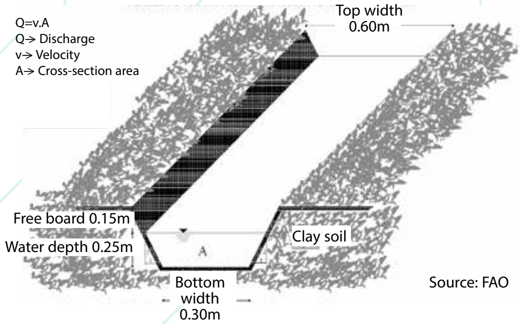
Figure 59: Re-designed tertiary canal profile with appropriate dimensions



Source: FAO

The recommended dimension considered the soil type, the irrigated land size and required nominal discharge and the average velocity:

- The irrigated land per tertiary canal is around 7 ha, one farm has a size of 3.4 ha. Two tertiary canals operate at the same time with 30 l/s nominal and 90 l/s maximum discharge. The average velocity in the tertiary canals is around 0.6 m/s.
- The average slope of the tertiary canals is steeper than 1.9 percent, but the earth is stable (clay and loam), thus, allowing a side slope of 49 – 60° according to the standard values.

Based on the spacing between the farms and the lateral offtakes from the secondary canals, the recommended dimensions of the trapezoid canals are: 0.6 m top width, 0.25 m depth and 0.3 m bottom width.

Water use efficiency measure: removal of undesired vegetation

The earthen canals were exposed to the rapid growth of undesired vegetation. Around the gates and canals, the bush made the structure inaccessible. In addition, the weed was decreasing the productivity of the crops. Although the intensive growth requires frequent manual weeding and the application of herbicide, weeding was not included in the daily maintenance works of farmers.

The manual weeding and possible application of certified and recommended herbicide (pre-emergent) are necessary to clean the canal bed, banks and its environment. Also, irrigation practice can help controlling the weed. Instead of applying water over the entire area (e.g. basin irrigation, flooding etc.), the furrows help spatial application of water to keep the moisture content of the root zone and to suppress proliferation of weeds. The entire scheme applies furrow irrigation, so adequately designed furrow can significantly decrease the need of herbicide, particularly the applied amount directly on the farms.

Figure 60: Distribution box and the border of the farm covered by weed

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Figure 61: Upland rice with short-line furrow irrigation after weeding

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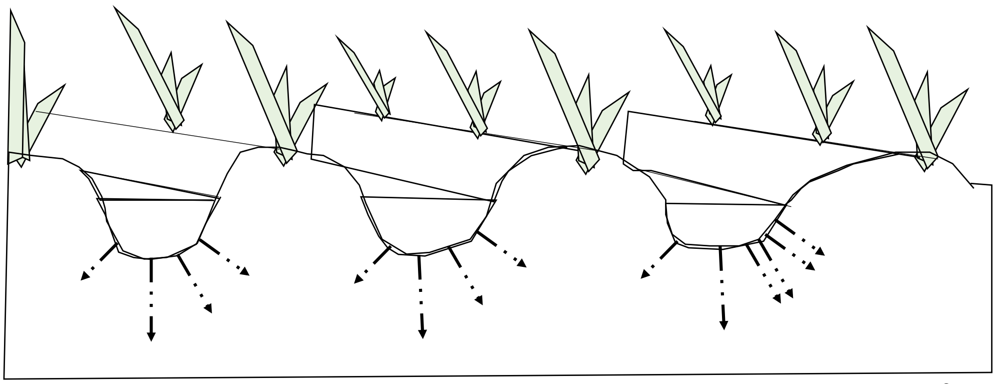
Figure 62: Water infiltration through furrows



Source: FAO

Water use efficiency measure: maintain the hydraulic structures – sluice gates and distribution boxes

Distribution boxes are useful for effective and equal distribution of water among the ditches, but they require proper maintenance. Boxes were hit by overtopping, so erosion occurred around the structure. The soil erosion led to the falling of the grounding and to the complete deterioration of the structure. Furthermore, missing valves were not replaced, but replicated with grasses, so it did not provide impermeable closing.

Distribution boxes are not prepared for water offtake, rather the gates are designed for water withdrawal, while boxes are deployed for distributing water. Therefore, each outlet has its own valve (4 in total) to protect the canal and the lands from unintended water flow. Each type of distribution box has its own design capacity, which should not be exceeded. After the rehabilitation of the tertiary canals, water level can be registered by scaling the outlets, thus, helping farmers calculating the applied water amount. If the valves are lost, the replacement should follow the original design in terms of dimensions and material:

- The sizes should follow the dimensions of the original valves or the size of the exit to ensure watertight closing.
- The valves are usually made of stainless steel, but painting and surface treatment are recommended to avoid rusting.

The adequate levelling of the boxes was fixed to protect the entry section of the canal. If the box is grounded high, the water drop will damage the earthen canal; if the box is below the ground level, the water conveyance becomes disturbed, and backwater effect occurs.

Figure 63: Flooded distribution box

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Water resources monitoring

Discharge measurement is a multi-objective activity considering the relationship between water supply and crop water productivity, and the monitoring of optimal water allocation to enhance water use efficiency. The consistent measurement processes enable water users to identify the most appropriate means of establishing water use records, and defining management rules. The insufficient irrigation infrastructure and lack of harmonized water-management leads to considerable water losses that eventually translated into lower productivity levels. Proper data acquisition is at the core of increased water use efficiency and Crop Water Productivity. This section presents the concept, methodology and possible implementation of water monitoring in small-scale schemes.

Irrigation scheduling to obtain water balance at field level

In simple terms, irrigation scheduling determines when to irrigate, how much water to apply, and when to start and stop the irrigation. Successful irrigation depends on a careful balance between water application and the crops’ response. As such, calculating the accurate irrigation schedule is essential to develop irrigation strategies for each field. In diversified multi-cropping systems, the irrigation schedule must be established on a case-by-case basis. This should be based on long-term data, observation, experiences and scientific evidences. Afterwards, it can be complemented and adjusted by short-term observations and real-time measurement.

There are many types of irrigation scheduling such as fixed rotation, proportional flow, scheduled by expert judgement, matching water supply with water demand in real-time. The scheme management establishes the management rules including irrigation scheduling, but farmers have often the flexibility to adjust the water service to their crop needs. Three methods are common in small-scale farming to calculate crop water demand/requirement2:

- Plant observation method: the simple observation method is based on the farmers' experience who regularly visit the field and observe the changes in characteristics such as colour changing, curling leaves or growing. There is a vast number of limitations in this method. For example, if the plant suffers from water stress, the signs appear often too late and the growth slows down. Each crop has different responses to water stress, if farmers rotate their crops, they must be aware of the different characteristics.
- Estimation method: the estimation method is based on pre-defined crop water requirement. Each irrigation scheme has an evidence-based calculation on the bulk water demand per each crop. This considers the evapotranspiration, the local weather trends, the soil types, the estimated root depth, and the irrigation method. Farmers then adjust their irrigation practice according to the real-time events.
- Simple calculation method: the method determines the irrigation schedule based on estimated depth of the irrigation application and the calculated irrigation water need by the crop over the growing season. The simple calculation method is more accurate than the estimation method because it considers the real-time water demand. As a first step, the net and gross irrigation depth is estimated. Subsequently, the irrigation water need over the total growing season is calculated. Then the number of irrigation applications over the total growing season is computed, and finally, the irrigation interval is calculated.

On the other side of the balance, water supply can be excessive or limited. However, irrigation practitioners have to attempt to match water supply to water demand regardless of the amount of water supply. In order to meet water demand, water supply must be calculated accurately.

How to determine water supply

Water supply comes from two major sources: effective rainfall and irrigation water resources (surface external, internal source3 or groundwater). If the rainfall is sufficient to meet water demand, irrigation is not required. Rain-fed irrigation remains the most common agricultural production form in Africa, although, rainfall is not enough in most of the cases, and farmers experience significant yield loss due to water stress. Quantifying both rainfall and discharge of irrigation water resources helps understanding crops yield response and avoiding uncertainties.

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[2] More information about crop water demand is available in the next publication of Farmers' Manual: Farmers' Manual to improve Water Productivity

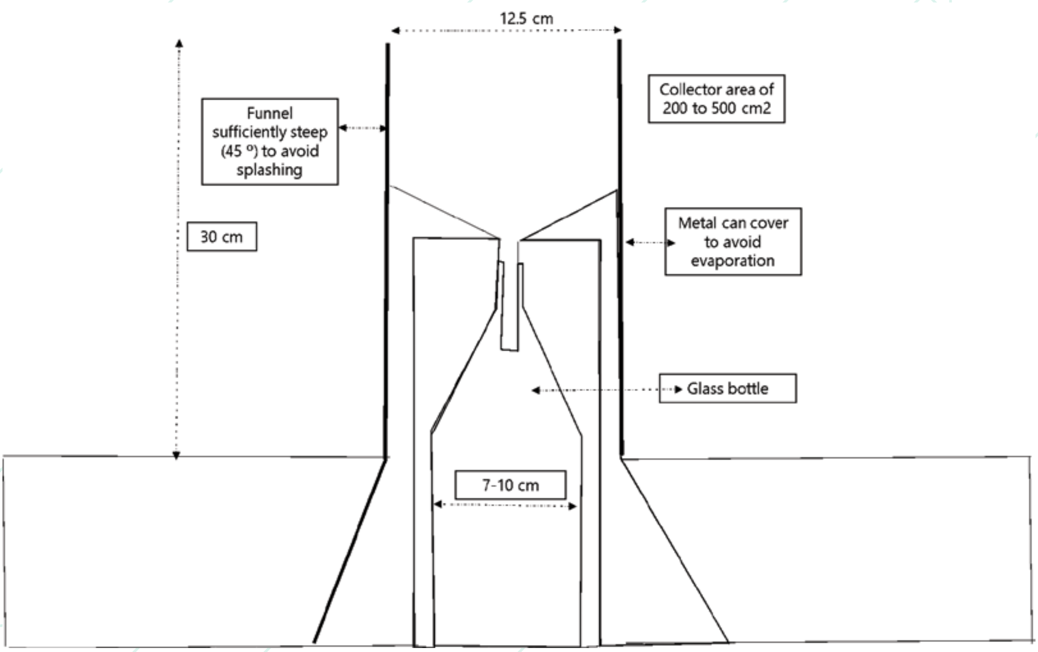
[3] The surface external water source refers to an inflow coming from outside, such as river, pumped water from stores, diverted water etc. The internal surface water refers to the recirculated water within the scheme boundaries (drain use, stored runoff, returning flow etc.).

Calculating rainfall

The rainfall can be measured by simple equipment produced locally. Raingauges are the most common structures to measure the precipitation in mm. The typical raingauge has a cylindrical form equipped with a funnel. The collector usually has a collecting area between 200 to 500 cm^2. The slope of the funnel is sufficiently steep to avoid the splashing. Raingauges are stainless steel, fiberglass or plastics. Figure 64 presents a typical raingauge, but the diameter, height and the manner vary considerably per country. The siting is one of the most important conditions, because the gauge must be installed in an open place where buildings, trees and other objects do not disturb the rainfall. The rim of the raingauge must be always horizontal. For the measurement, graduated measuring cylinder, dipstick or rod should be used.

Not all the rainfall is used by the plant as part of it is lost due to deep percolation or runoff. The part stored in the root zone and used by the plants is the so-called effective rainfall (Pe). The factors that influence the ratio between effective and non-effective rainfall are many, such as climate, soil type, and soil structure, depth of the root zone, topography, and irrigation practices. Nevertheless, the two major causes are the deep percolation and the runoff. Deep percolation occurs when the soil is still wet and not able to store more water, and water percolate below the root zone. The runoff is the result of insufficient levelling of the lands and perhaps high velocity. In irrigation schemes, the formula to determine the ratio between effective and non-effective rainfall is usually developed locally, based on empirical evidences. Nevertheless, rough estimation is available to calculate the effective rainfall in normal conditions. Table 11 provides the effective rainfall of total rainfall amount per month, where P is the total rainfall and Pe is the effective rainfall in mm.

Figure 64: Raingauge with typical dimensions



Source: FAO

Discharge measurement

Irrigation water source can be groundwater and surface water, and surface water can be external or internal resources. The closer is the measurement to the irrigated farms, the more accurate data can be acquired to estimate the applied water amount. In irrigation, water supply is expressed usually in discharge. The discharge is the volume of water that is conveyed in a second. The unit is indicated usually either in litres (l/s) or in cubic meters (m^3/s).

Water discharge can be calculated through the following formula:

$$Q=A*v$$

Where

Q=discharge (m^3/s)
A=cross-sectional area of flow (m^2)
v= average flow velocity (m/s)

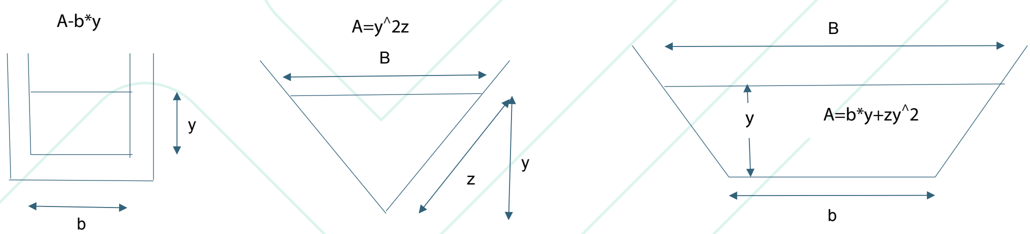
Table 11: Effective rainfall per total amount of rainfall (FAO - Irrigation Water Management, Training manual Number 3)

P (mm/ month)	Pe (mm/ month)	P (mm/ month)	Pe (mm/ month)
0	0	130	79
10	0	140	87
20	2	150	95
30	8	160	103
40	14	170	111
50	20	180	119
60	26	190	127
70	32	200	135
80	39	210	143
90	47	220	151
100	55	230	159
110	63	240	167
120	71	250	175

The cross-sectional area of flow can be calculated from the dimensions of the canal. The formulas of some of the typical cross-section are below:

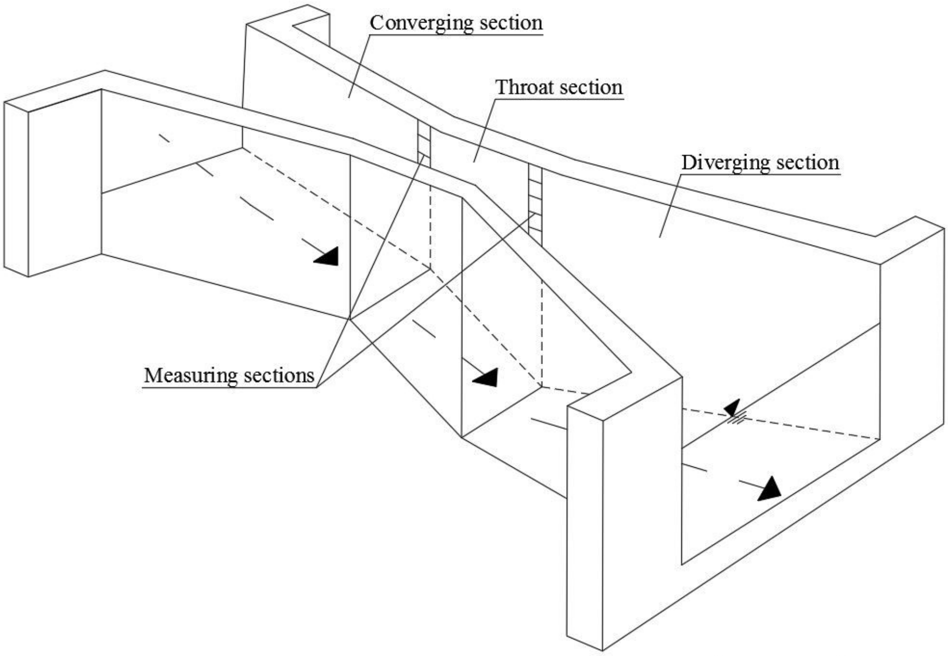
The calculation of average velocity (v) is more difficult as it requires specific devices or hydraulic structures such as the already presented "modules à masques". The most common structures are Parshall flumes or weirs. The structures are either portable (mobile Parshall flume) or locally installed. One of their most important advantages is that the accurately constructed structures are already calibrated, and the users simply read the graded gauge to directly calculate the discharge. The disadvantage is their inflexibility or sensitivity. Since they are made of solid material such as concrete, the installed flumes or weirs cannot be replaced, and are exposed to deterioration.

Figure 65: Calculation of typical cross-section area



Source: FAO

Figure 66: Parshall flume



Source: FAO

If the devices are not available, Manning formula is established to give a rough estimation of velocity in open channels:

$$v = K_m R^{2/3} s^{1/2} = \frac{1}{n} R^{2/3} s^{1/2}$$

as

R=A/u

A=by+ay2

v=Q/A

Where

A= cross-sectional area of flow (m^2*); B= bottom width (m); Km=1/n=roughness coefficient (m1/3/s); Q=discharge (m*^{3}*/s); R=hydraulic radius (m); S= hydraulic gradient (-); u= wetted perimeter (m); v=average flow velocity (m/s); y=water depth (m); a=coefficient in side slope*

Manning formula assumes a stable and steady flow, which is a rare case in open-canals. Canals are often not regular and flow can be disturbed. Therefore, regular velocity measurement with accurate devices is recommended to establish the so-called rating curve and enable the calculation of the discharge from the water level. Each velocity measurement device has its own instruction and intended use. In order to calculate the discharge correctly, the manufacturer instructions should be followed. Most of the real-time measurement method is based on rating curve methodology.

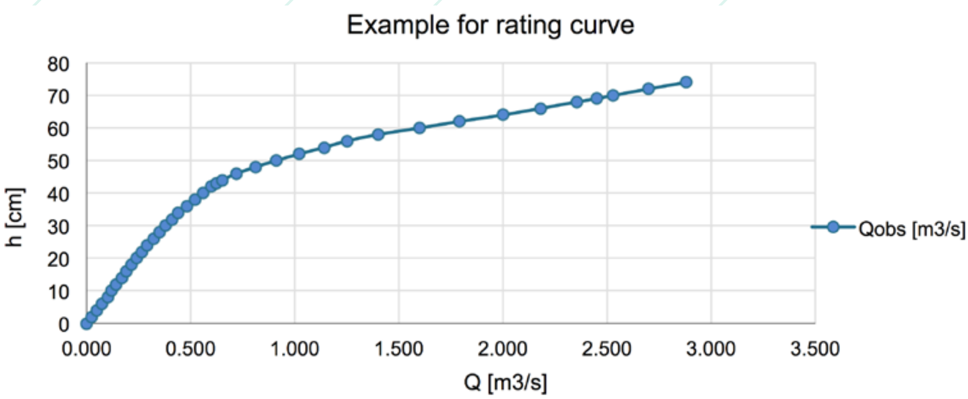
While calculating the discharge (by the formula: Q=A*v) at different water levels, a relationship can be established among them.

In other words, the combinations of discharge values and the related water levels result in the equation of their relationship.

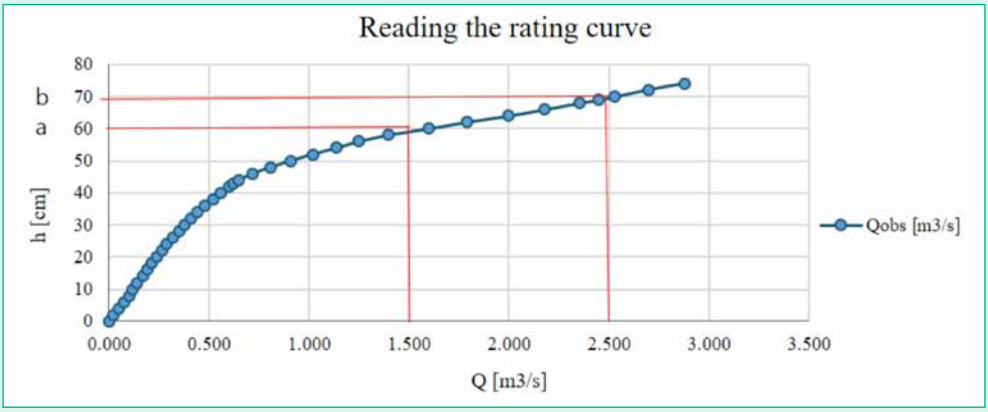
Q=f(h)

Where
Q=discharge
f(h) = algebraic function of water level

The rating curves are unique and each canal section has its own rating curve according to the canal characteristics. In order to obtain information on the water supply in the canal, the site selection of the measurement must be based on pre-defined criteria system. The criteria system can be established by the following requirements: type of water sources, scale of measured water supply (scheme level or farm level), flow behaviour (steady or rapidly changing), etc. Usually, the water level appears on the 'y' axis (h, cm), and the discharge value is on the 'x' axis (m^3/s or l/s). The more measurement is taken, the more accurate rating curve can be established. Once the rating curve is set-up, the users can read the water level and estimate the discharge.



Example of reading a rating curve and calculating irrigation water supply



'a' reading shows 60 cm water level (at 'y' axis). Reading the curve along shows that the discharge is 1.5 m^3/s (at 'x' axis) at 60 cm.

'b' reading shows when the water level elevates to 70 cm. The concurrent discharge value based on the curve is 2.5 m^3/s.

Converting discharge to stock water supply enables the matching to water demand. The conversion is:

1 l/s = 0.001 m^3/s → considering 12 hours long irrigation per day → 1 litre * 60 seconds * 60 minutes *12 hours = 43 200 litre per day = 43 m3 water supply per day

Converting the rainfall values to stock water supply must be added to the daily water supply. The conversion is:

1 mm = 1 l/m^2 = 0.001 $m3/m^2$

1 ha = 10 000 m^2

10 mm rainfall per day → 10 l/m^2 → 100 000 l/ha → 100 m^3/ha

Example:

- 20 l/s flow discharge for 1 ha during 6 hours = 20 liter * 60 seconds * 60 minutes * 6 hours = 432 000 liter water supply per day
- Convert the liter to m^3: 1000 l = 1 m^3 → 432 000 liter = 432 m3.
- Daily rainfall = 14 mm
- Convert he rainfall to m^3: 1 mm/m^2= 1 $liter/m^2$ → 10 000 l/ha = 10 m3/ha →14 mm/day = 140 m3/ha
- Total water supply per day = 432 m^3 + 140 m^3= 572 m^3

Discharge Monitoring Protocol

*To be completed on daily base

Name ____ Date ______________________________

1. Water sources

1.1. Rainfall

Rainfall amount: _______mm/day Effective rainfall:_______mm/day

Conversion: a rainfall of 1 mm= 0.001 m3, or

1 litre of water to each m^2 of the field

Water supply from rainfall: _______m^3/day

1.2. Irrigation water resource

- Open-canal entering the field
- Groundwater sources conveyed by open-canal
- Stored water conveyed by open-canal
- Other water resources

2. Instructions for discharge monitoring in open-canal

- Ensure that the measured water supply is the only water source for your farm
- Monitor water discharge only in irrigation days.
- Monitor each irrigation day including the ones when you receive non-scheduled flow such as excess water from upstream farms.
- Take measurement as frequently as possible – depending on the stability of the flow, but at least at the beginning and at the end of the irrigation. If the water level is fluctuating, take measurement every half an hour.
- The measurement must be taken at identified measurement site.
- If the canal profile deteriorates at the measurement site, the original shape must be re-formed.
- Before you take measurement, be sure that the flow is stable and nothing disturbs it upstream and/or downstream from the measurement point.
- Calculate the average discharge from the measurements per day.
- Estimate the daily rainfall.
- Consider the discharge and rainfall data and calculate the daily water supply by converting the discharge to stock number.

Do not forget to record the measured discharge values and preserve it in a logbook. It may give you precious information on the yield response to the water supply.

Discharge monitoring in irrigation season is the basis of calculating the amount of applied water. But, monitoring must follow a strict protocol in terms of time. Farmers receive water according to the irrigation schedule established by the scheme management. Irrigation schedule determines the duration and the frequency of the irrigation per farm. Afterwards, farmers can create their monitoring protocol. The following protocol is an example to collect accurate discharge data.

Establishing discharge monitoring system: country cases

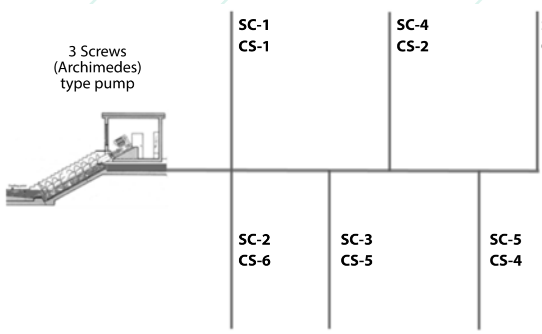
Each irrigation scheme has its own characteristics which determine the most fitting monitoring system. Although discharge measurement is the backbone of irrigation scheduling, none of the pilot schemes in the three countries have established monitoring system yet. Water distribution in all the schemes is based on fixed rotation regardless the weather condition and the types of crops.

The established monitoring systems aimed at providing practitioners with information on the overall water supply of their schemes. Also, discharge history was established during the piloting period in order to investigate the accuracy of the recommended monitoring systems.

Water discharge monitoring in Ben Nafa Kacha, Burkina Faso

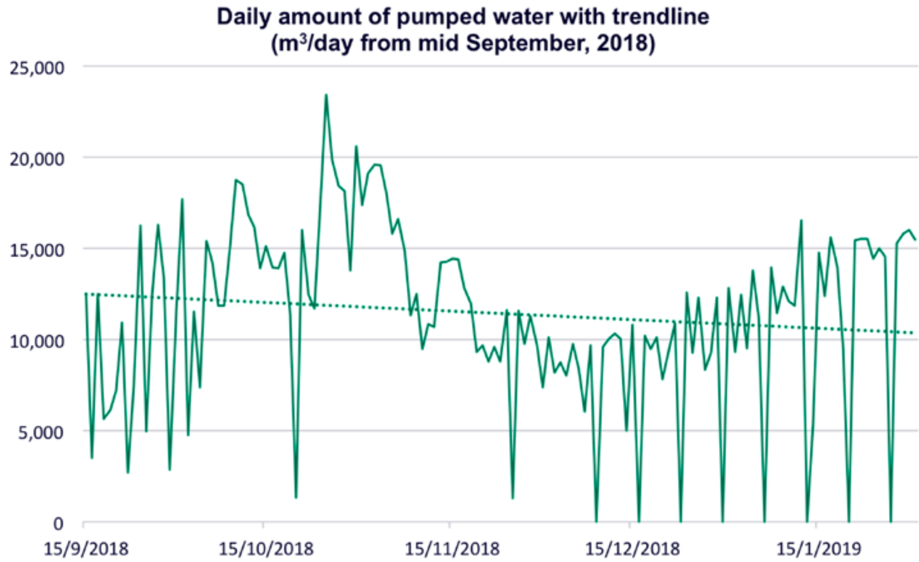
Irrigation campaign starts from October until March with the basin filling of the paddy rice plots. The irrigation scheme has a pumping station with three "Archimedes screws" with a height of 4.3 m and a 300 l/s discharge each. During the basin filling period, the three screws are used simultaneously to obtain the maximum discharge of 900 l/s, and the capacity of the main canal is sufficient to store water temporary. The main canal is connected to 6 secondary canals, each providing water by rotation to five tertiary canals. The total number of tertiary canals in the area is 30. The majority of these tertiary canals (25 canals) provide water to 10 ha each, while five tertiary canals irrigate only 5 ha each. Water distribution is based on rotation in a way that each plot is irrigated once every five days and each irrigation turn provides water through a tertiary canal to 2 ha simultaneously.

Pumping starts in the middle of September to fill-up the main canal and store water for basin filling. The average daily irrigation volume is 11 400 m^3 during 8-10 hours operation. Since two tertiary canals irrigate around 20 ha at the same time, the water supply provides around 500 – 600 m^3/ha of irrigation water per irrigation turn. In an irrigation campaign, farmers receive around 4 000 m^3 of water supply for 1 ha without considering the water loss through conveyance. The irrigation turns are rotated in fixed delivery schedule.



Source: FAO

Figure 67: Obtained discharge history of the Main canal

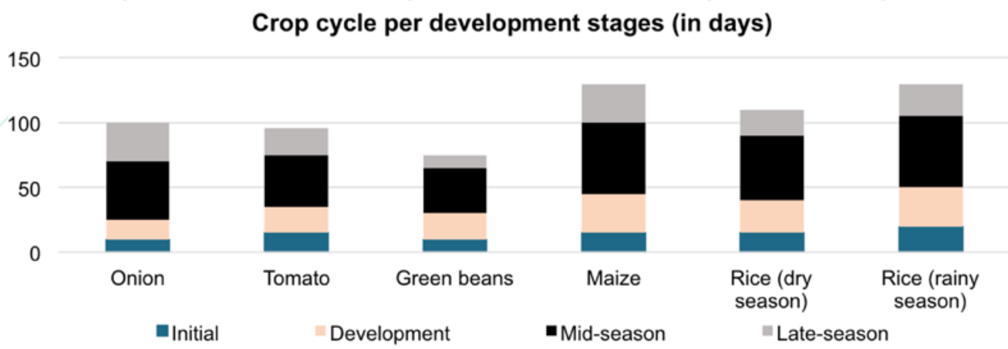


Source: FAO

Maize and rice have the longest crop cycle with 130 days, the last plots are harvested in late February. Each season the crop cycle is broken down according to development stages into: initial, development, mid-season, and late-season stage. The agronomic practices vary among farmers in terms of time of sowing/seed planting, applied agronomic technologies, applied inputs, time of harvesting. The crops are irrigated through a furrow system, except for the paddy rice, which is cultivated with recession.

Table 12 shows the water requirements of the crops compared to the actual water supply and Figure 69 shows water balance at farm level, according to the field experiences.

Figure 68: Crop cycle per development stages in Ben Nafa Kacha scheme

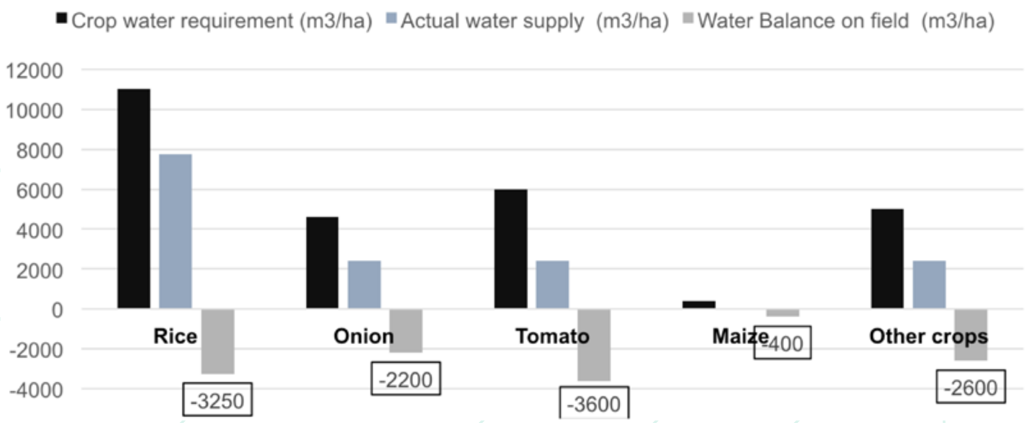


Source: FAO

Table 12: Water demand and supply matching in Ben Nafa Kacha scheme

	Irrigation method	Crop water requirement (m^3/ha)	Theoretical water supply (m^3/ha)	Water use efficiency (%)	Actual water supply (m^3/ha)
Rice	Recession	11 000	12 920	60	7 750
Onion	Furrow	4 600	3 990	60	2 400
Tomato	Furrow	6 000	3 990	60	2 400
Maize	Furrow	400	Rain-fed	-	-
Other crops	Furrow	2 000 – 8 000	3 900	60	2 400

Figure 69: Water Balance at farm level per crops in Ben Nafa Kacha



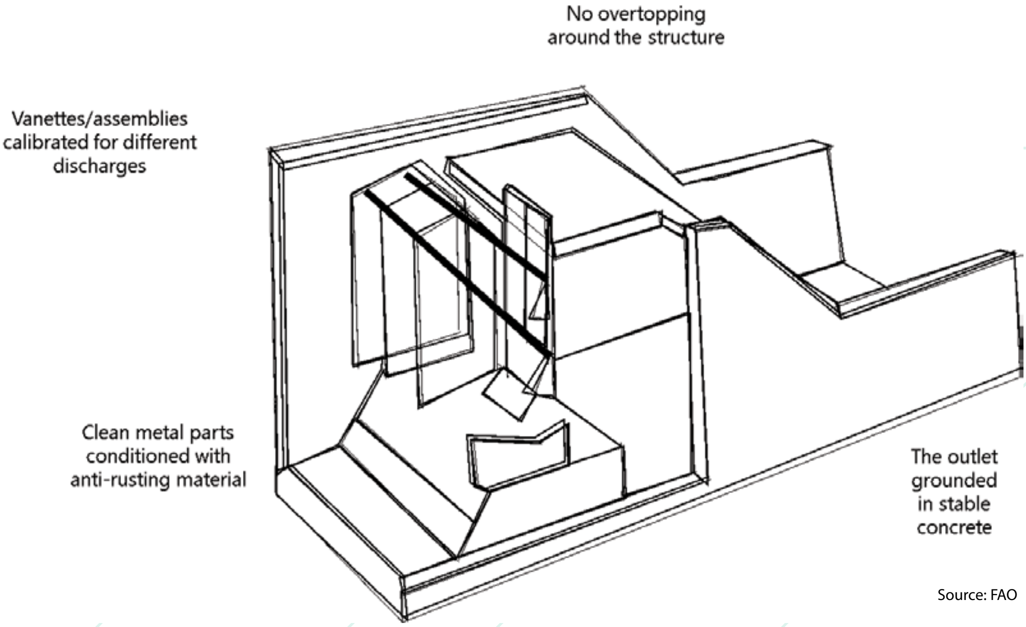
Source: FAO

Although the theoretical water supply – pumped water – would be sufficient for irrigation, the water losses significantly reduce the amount of available and productive water. Moreover, the rotated irrigation turns provide large water supply, but the majority of it ends up in the drains. Adjusting actual water discharge to crop water requirement would enhance farm-level water use efficiency while not exceeding the 30 l/s discharge allocation at tertiary canal level.

Discharge monitoring system

In the scheme, there are 36 "modules à masques", 6 along the main canal (1 of the type XX290 and 5 of the type XX2150) and 30 of the type X130 along the secondary canals. Each tertiary canal has "modules à masques" intakes, which regulate and control water. The modules à masques should be well maintained to provide accurate discharge information. The grounding must ensure that no leakage appears around the structure, and the flow should be regulated to avoid the overtopping. Each moveable "vannettes"/assemblies must be functional and complete.

Figure 70: Maintenance of the "modules a masques" for discharge measurement



Source: FAO

The "modules à masques" come with manufacturers' recommendations. Each flow volume has its suggested operation mode. The discharge capacities of the main types are:

- Série X: 10 l/s/dm= 1 l/s/cm
- Série XX: 20 l/s/dm= 2 l/s/cm
- Série L: 50 l/s/dm= 5 l/s/cm
- Série C: 100 l/s/dm= 10 l/s/cm

The types are also differentiated according to their suitability to the design flow. The main and secondary canals are equipped with Série XX290 and XX2150 types within Série XX. The design capacity per "vannette" is the following:

Modules XX1 and XX 2						
Discharge	Number of "vannettes"					l
Number	10	20	30	60	90	Enc.
l/s	l/s	l/s	l/s	l/s	l/s	cm
30	1	1				16
60	1	1	1			32
90	1	1	2			48
120	1	1	1	1		63
150	1	1	2	1		79
180	1	1	1	2		94
210	1	1	1	1	1	109
240	1	1	1	3		125
300	1	1	1	1	2	155
360	1	1	1	2	2	186
420	1	1	1	3	2	217
480	1	1	1	1	2	247

The Série X has two different types of modules: X1 and X2. X130. The one installed as intake of the tertiary canals has the smallest capacity with 30 l/s. These "modules à masques" have only 3 "vannettes" with 5, 10 and 15 l/s discharge capacity. The intakes of the tertiary canals have the following capacity:

If the users record the number of the open "vannettes" and the duration, they can calculate the discharge. Nevertheless, they have to ensure that no overtopping occurs around the structure and the tertiary canal does not receive other inflow.

The users have also to calculate the average water use efficiency and the difference between the supplied and the applied water at farm level. A 60 % average efficiency was taken into account, but this value can vary according to different factors explained in previous sections (evaporation, runoff, percolation etc.)

Modules X1 et X2

Discharge	Number of "vannettes"					I
Number	**5**	**10**	**15**	**30**		**Enc.**
l/s	**l/s**	**l/s**	**l/s**	**l/s**	**l/s**	**cm**
30	1	1	1			32
60	1	1	1	1		63
90	1	1	1	2		94
120	1	1	1	3		125
150	1	1	1	4		156

The following monitoring protocol is compiled for farmers to record and log the water supply by using the "modules à masques". Comparing then the water supply to the crop water requirement helps establishing an appropriate irrigation schedule.

Water discharge monitoring in Haouz 3 Sector, Morocco

The main, secondary and tertiary canals are equipped with "modules à masques". Farmers receive water from the tertiary canals, and the mounted structures drop water into the distribution boxes. Since the water loss is significant during the distribution from tertiary canal to quaternary

Example of water supply calculation by "modules a masques"

2 "vannettes" of Série X130 modules à masques are open for 8 hours during an irrigation turn, which means 5 l/s + 10 l/s discharge during 8 hours.

15 l/s * 8 hours → 15 l * 60 seconds * 60 minutes * 8 hours = 432 000 l = 432 m^3 daily water supply.

The following factors decrease the efficiency:

- Lack of water distribution structures from tertiary canal to quaternary canals → massive amount of runoff into the drains
- Due to wind and high temperature, water evaporates without reaching the fields → evaporation losses
- The soil is sand or sandy-loam, the soil permeability is high →massive amount of deep percolation losses
- The entry phase of the tertiary canals are widened, so waterlogging occurs → runoff losses

Considering the identified problems above, the overall efficiency of the conveyance system is 60 %.

Correcting the overall daily water supply by the efficiency rate, the calculated effective water supply applied on farm is 259.2 m^3.

Discharge monitoring logbook

"Modules a masques" Serie X1[30]

*To be completed on daily base

Name ____________________ Date ____________________

Irrigation turn	Date	"Vanettes" (open or not)			Duration of opening (hours)			Water supply (m3)	Water use efficiency (%)	Applied water amount (m^3)
		5 l/s	10 l/s	15 l/s	5 l/s	10 l/s	15 l/s			
1st										
2nd										
3rd										
…										
…										
…										
…										

canals, sequential water monitoring is recommended. In order to carry out accurate discharge measurement, water should be measured at the intakes ("modules à masques") and in the quaternary canals.

The scheme is hit by water scarcity, therefore, water loss should be minimized through maximizing water use efficiency. Consequently, discharge monitoring has multiple objectives in this case. The primary objectives are:

- Matching the water supply to the crop water requirement.
- Identifying the key factors and locations of the water loss.
- Monitoring water resources and set-up early warning system through discharge data acquisition.

The offtake structures between canals are "modules à masques" from Serie X and Serie XX types. The structures must be monitored according to their discharge capacity. The manufacturer instructions provide information on the design discharge of the structures. In order to identify the water loss, the discharge should be monitored level-by-level, starting from the intake of the secondary canals. By selecting the type of the "modules à masques" and recording the number of open "vannettes" and the duration of the opening, the water supply can be calculated.

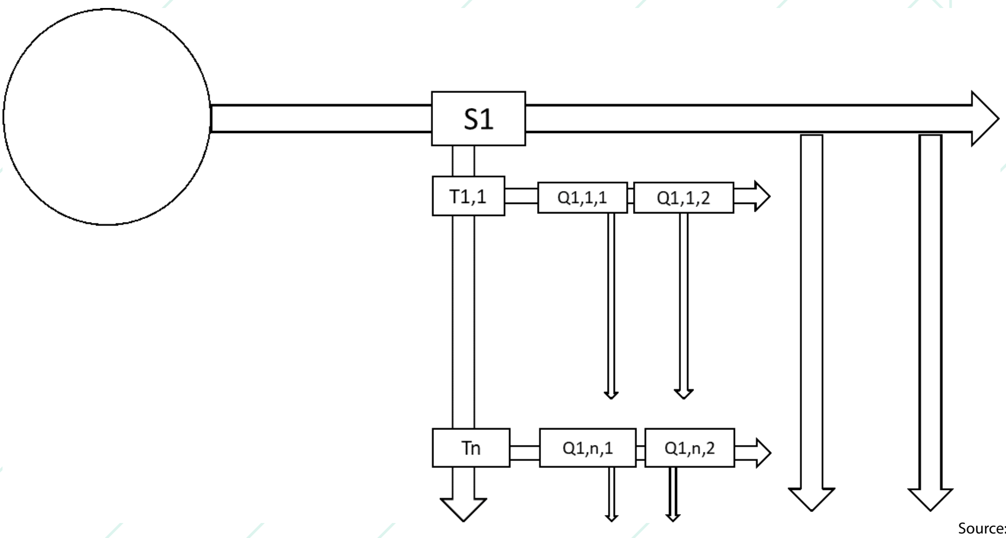
Modules X1 et X2						
Discharge	Number of "vannettes"					I
Number	5	10	15	30		Enc.
l/s	l/s	l/s	l/s	l/s	l/s	cm
30	1	1	1			32
60	1	1	1	1		63
90	1	1	1	2		94
120	1	1	1	3		125
150	1	1	1	4		156

Modules XX1 and XX 2						
Discharge	Number of "vannettes"					I
Number	10	20	30	60	90	Enc.
l/s	l/s	l/s	l/s	l/s	l/s	cm
30	1	1				16
60	1	1	1			32
90	1	1	2			48
120	1	1	1	1		63
150	1	1	2	1		79
180	1	1	1	2		94
210	1	1	1	1	1	109
240	1	1	1	3		125
300	1	1	1	1	2	155
360	1	1	1	2	2	186
420	1	1	1	3	2	217
480	1	1	1	1	2	247

The following tables include the design capacity per "vannette" of each type of Serie X and XX "modules à masques":

The following schematics present the methodology of sequential water monitoring in the scheme. If an upper level canal supplies a number of lower level canals at the same time, the monitoring should be carried out in the simultaneously operating canals. After considering the simultaneous operation, the difference between the levels can then be compared only if there is no productive water use through the conveyance (irrigation directly from the upper level canal).

Figure 71: Schematics of sequential discharge measurement



Source: FAO

Modules XX1 and XX2											
Discharge	**Number of "vannettes"**										
Number	**10 l/s**	**Duration (h)**	**20 l/s**	**Duration (h)**	**30 l/s**	**Duration (h)**	**60 l/s**	**Duration (h)**	**90 l/s**	**Duration (h)**	**Total water supply**
Design capacity 'x'											

T1 – Tertiary canal (simultaneous operation with other tertiary canal)

Modules X1 and X2									
Discharge	**Number of "vannettes"**								
Number	**5 l/s**	**Duration (h)**	**10 l/s**	**Duration (h)**	**15 l/s**	**Duration (h)**	**30 l/s**	**Duration (h)**	**Total water supply**
Design capacity 'x'									

Tn – Tertiary canal (simultaneous operation with other tertiary canal)

Modules X1 and X2									
Discharge	**Number of "vannettes"**								
Number	**5 l/s**	**Duration (h)**	**10 l/s**	**Duration (h)**	**15 l/s**	**Duration (h)**	**30 l/s**	**Duration (h)**	**Total water supply**
Design capacity 'x'									

S1 – T1 – Tn = Water loss through the conveyance from secondary to tertiary canals

Between the mounted tertiary canals and the ground level quaternary canals, water is dropped, so significant water loss occurs. Therefore, matching water supply to crop water requirement requires discharge monitoring in quaternary canals. The profile and the conditions of the quaternary canals do not allow carrying-out precise measurement. The suggested rehabilitation with geomembrane not only helps to reduce the water loss, but also enables the discharge measurement. Depending on the construction level, the previously mentioned Manning formula is applicable on the rehabilitated sites:

$$v = K_m R^{2/3} s^{1/2} = \frac{1}{n} R^{2/3} s^{1/2}$$

Where

K_m=1/n=roughness coefficient ($m^{1/3}$/s) is estimated from the manufacturer data of the geomembrane à 70 $m^{1/3}$/s; R = hydraulic radius (m) estimated from the suggested rectangular shape of the canal; S=Hydraulic gradient

In other words, the discharge (Q) of the rectangular quaternary canals can be calculated by the following equation:

$$v = K_m \, b y^{5/3} s^{1/2}$$

and

$$Q = A \, v$$

The difference between the measured discharge in the quaternary canals and intake ("modules à masques") is the water loss occurred through water intake into the quaternary canals.

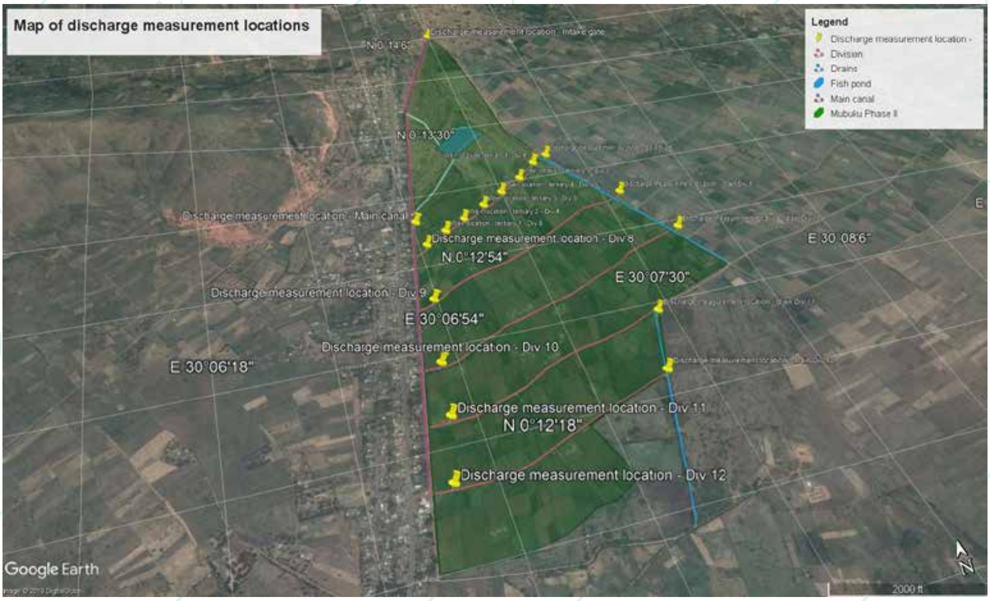
Water discharge monitoring in Mubuku, Uganda

In Phase II (176 ha), the source of water of Mubuku scheme is the Sebwe River and water is distributed to five secondary canals (so called 'Divisions': B 8, B 9, B 10, B 11 and B 12) from the main canal. Water is conveyed directly to farms (holdings) through tertiary canals. Two discharge measurement techniques were introduced to establish accurate, sustainable and scalable measurement system in the scheme: (1) weir measurement, and (2) non-contact discharge application (LSPIV).

The selection of measurement sites considered a number of criteria. In order to obtain information on the withdrawn water, measurement location was installed at the headworks. The second measurement location was selected along the main canal, after the returning flow from the fish pond, thus, considering the water use for environmental purposes. The rest of the measurement sites are installed at the entry stretch of the Divisions after the intake and before the first tertiary canal. In Division 8, each tertiary canals are equipped with weirs for flow regulation and discharge measurement. Furthermore, each drain per Division is equipped with weirs to measure the runoff. The structure of the monitoring system enables the following analysis:

- Measurement of the water withdrawal into the scheme.
- Measurement of the water use for environmental purposes.
- Equity of water distribution among the Divisions.
- Equity of water distribution among the tertiary canals.
- Runoff entering the drains.
- Overall water balance in the scheme by comparing the water withdrawal and the runoff.
- Water balance at field level by comparing the discharge with the crop water requirement in Division 8.

Figure 72: Map of discharge measurement locations

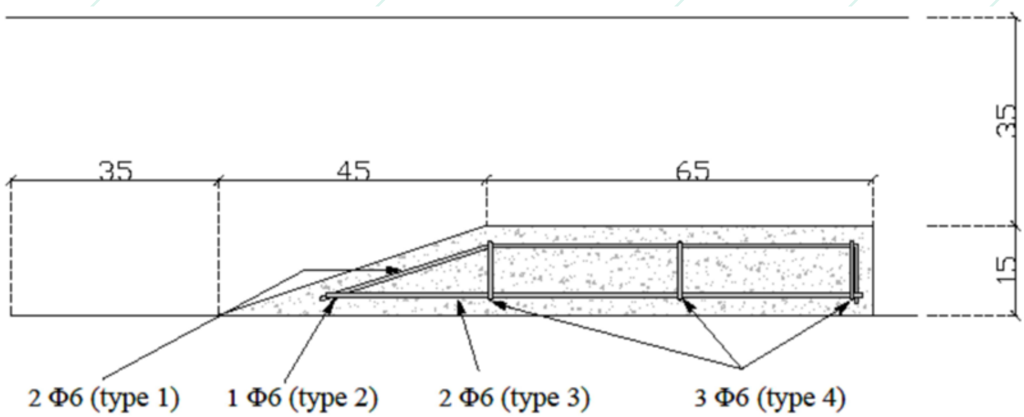


Source: CIHEAM BARI, 2018

Weir structures

Weirs consist of overflow structures to measure the volumetric rate of water flow. The main, secondary canals and tertiary canals, and drains were assessed to determine the positions (coordinate points) of the measurement sites. The selection was based on a geometric survey considering the canal section shape and the minimum distance from the upstream gate - varying between 50 and 30 m from the gates. The trapezoidal canal shapes, especially on the secondary canals, are not regular in several parts, showing lateral steps and restrictions that could lead to a biased flow rate calculation. Considering all, each selected point has been measured in three sections in order to determine the differences.

Figure 73: Cross-section of the weir in the main canal



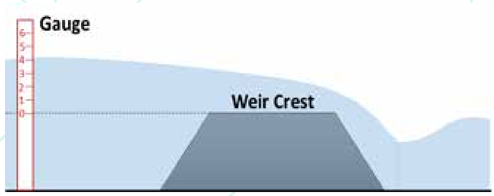
Source: ©FAO

The design considerations used for the main and secondary canals are:

- Flow rate max (Qmax)
    - Main canal: 350 l/s
    - Secondary canal: 200 l/s
- Flow rate min (Qmin)
    - Main canal: 60 l/s
    - Secondary canal: 50 l/s
- Slope (S)
    - Main canal: 0.0004 m/m
    - Secondary canal: 0.002 m/m
- Free board adopted is 10% on the h1
- Ratio between Qmax/Qmin
    - Main canal: 6
    - Secondary canal: 4

The weirs along the canals were calibrated and discharge curves were computed. Next to the weirs, gauge stations were installed for water level reading.

Figure 74: Schematics of gauge station at the weir



Source: ©FAO

Figure 75: Gauge station at the weir in the secondary canal

©FAO/Abdelouahid Fouial

Non-contact discharge application

The second measurement method is a crowd-sensing mobile application based on the Large Scale Particle Image Velocimetry (LSPIV) method, which measures velocity fields at flow surface. The LSPIV provides indirect measurement by recording continuous images of the flow surface, and using a cross-correlation algorithm to determine the most likely displacement of patterns. At dedicated measurement sites, the application can determine water level and discharge. The discharge is calculated either via rating curve, or via surface velocity that is measured by the app. The application is suitable to validate the calculated discharge from the water level reading as well, so after establishing the rating curve, the discharge can be calculated from the water level. An operational site requires four reference markers and calculated cross-sectional profile. The identification of a convenient measurement site along the river, channel or furrow is of major importance as it determines the measurement accuracy and a smooth setting-up and calibration procedure. The selection considers:

- Constant and well-defined cross-sectional profile of the stream.
- Accessibility at least at one side of the river section.
- Sufficient visible structures on the moving water surface, like turbulent patches, waves, leaves, bubbles, etc.
- Angel of the camera requiring as straight angle as possible.

- Minimized light contrast by avoiding the shadows (building, trees, etc.)
- Normal flow conditions (e.g. no backwater effects, etc.)

The application provides an easy solution to monitor water resources, but it has some limitations when applied to small flows. The platform is fully available online once the sites are set up. But, as it is in the case of the weir, the design must be proper and hydrology experts must be involved to define the best locations for the measurement sites.

According to the weir measurement in irrigation days, the total water supply in Phase II is 4.95 million m^3/year with 259 l/s average discharge in the main canal within +/- 5 % error range. Out of the irrigation schedule and the rainy days, the intake gate is closed and the irrigation system is set off. The discharge often exceeds the design discharge of the main canal due to the lack of control at the headworks and flow controlling structures along the canal.

Table 13 shows the unequal water distribution among the Divisions. The upstream divisions, such as 8 and 9, divert more water due to the weak enforcement of the irrigation schedule. Farmers cannot establish solid irrigation practices and downstream farms often suffer from water shortage due to this irregular and unequal water distribution among the divisions. In order to effectively comply the schedule and create equity, the intake gates of the divisions were equipped with locks.

This water over-supply results in a large amount of excess water, high discharge, and considerable runoff into the drains. For example, the average discharge in the drain of

Figure 76: Discharge measurement process with Discharge app

©FAO/Eva Pek

Figure 77: Interface of the Discharge application

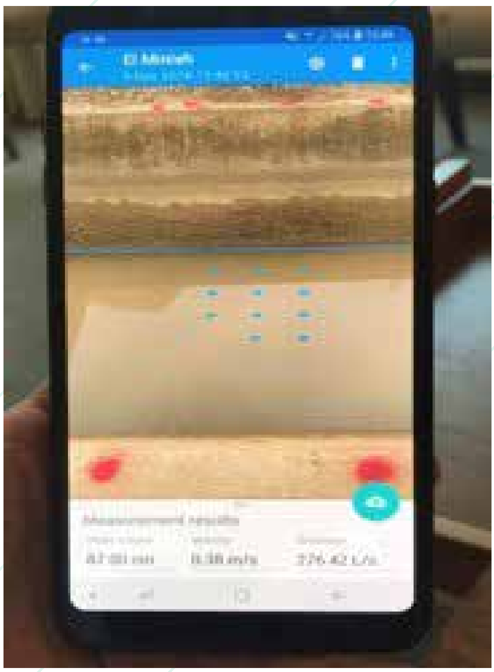


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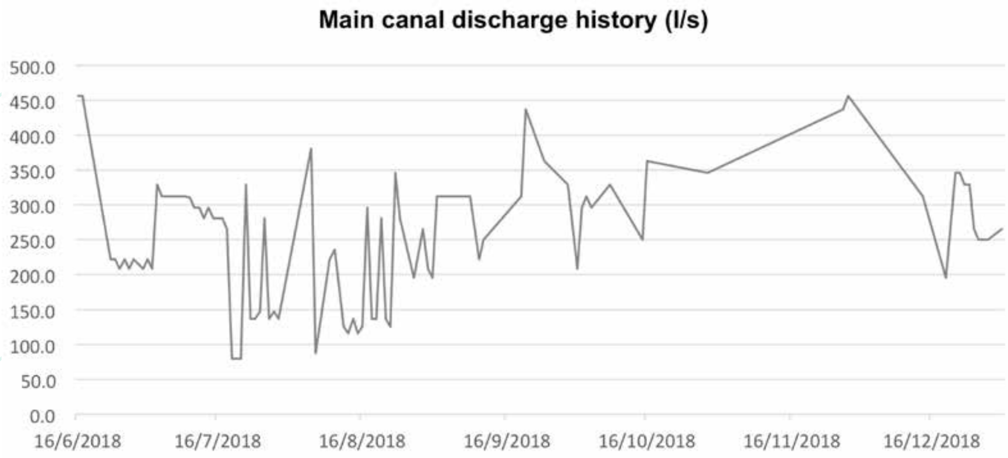
Figure 78: Discharge history in irrigation days in the Main canal



Source: ©FAO

Division 8 exceeds 42 l/s in irrigation days, which is around half of the average discharge in Division 8 secondary canal (100 l/s). Also, the comparison between the average discharge in the drain and the average discharge in the tertiary canals (46 l/s) indicates a massive runoff. The high discharge is not only water loss, but also cause damage to the hydraulic structures. Therefore, optimal water control should be introduced through adjusted irrigation scheduling and flow controlling structures.

The irrigation system is operated in both agricultural seasons and water is distributed by following dictated rotation. The irrigation schedule was established in consultation with Division leaders and farmers, but the proposed timetable has been slightly modified since 2014. The farmers follow dictated rotation in the following order:

- Division 8: 3 hours per farm after every 3 days i.e. twice a week.
- Division 9: 3 hours per farm after every 3 days i.e. twice a week.
- Division 10: 3 farms 2 hours and 8 farms get 3 hours water service twice a week.
- Division 11: 3 hours per farm after every 3 days i.e. twice a week while one farmer has 1 hour and 30 minutes in 7 day i.e. once per week.
- Division 12: 6 hours service after every 3 days i.e. twice a week.

Table 13: Summary statistics of the discharge per division

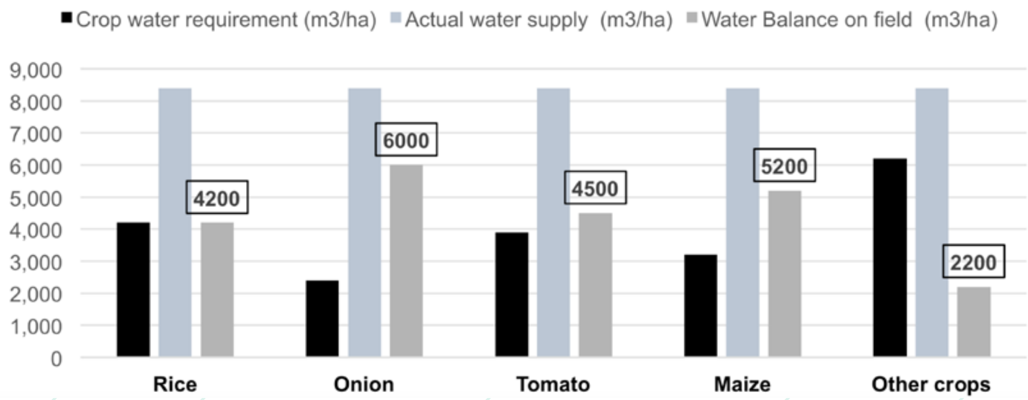
	Division 8	Division 9	Division 10	Division 11	Division 12
Average (l/s)	110.4	111.3	82.5	57.4	42.7
MAX (l/s)	252.2	240.8	177.8	138.8	74.4
MIN (l/s)	33.7	18.9	14.1	7.2	23.3
Standard deviation (l/s)	51.6	54.4	40.9	24.9	15.5

Table 14: Water demand and supply matching in Mubuku

	Irrigation method	Crop water requirement (m^3/ha)	Theoretical water supply (m^3/ha)	Water use efficiency (%)	Actual water supply (m^3/ha)
Rice (upland)	Furrow	4 200	14 000	60	8 400
Onion	Furrow	2 400	14 000	60	8 400
Tomato	Furrow	3 900	14 000	60	8 400
Maize	Furrow	3 200	14 000	60	8 400
Mango	Furrow	6 200	14 000	60	8 400

Table 14 summarizes the water requirement for each crop and Figure 79 shows the water balance at farm level, based on the field experience.

Figure 79: Water Balance at farm level per crops in Mubuku



Source: ©FAO

The theoretical water supply is almost 4 times more than the crop water requirement and the excess water flows through the farms and ends-up in the drains. Furthermore, water is not distributed equally, so downstream farmers experience water shortages while upstream farmers are hit by damaging high discharge.

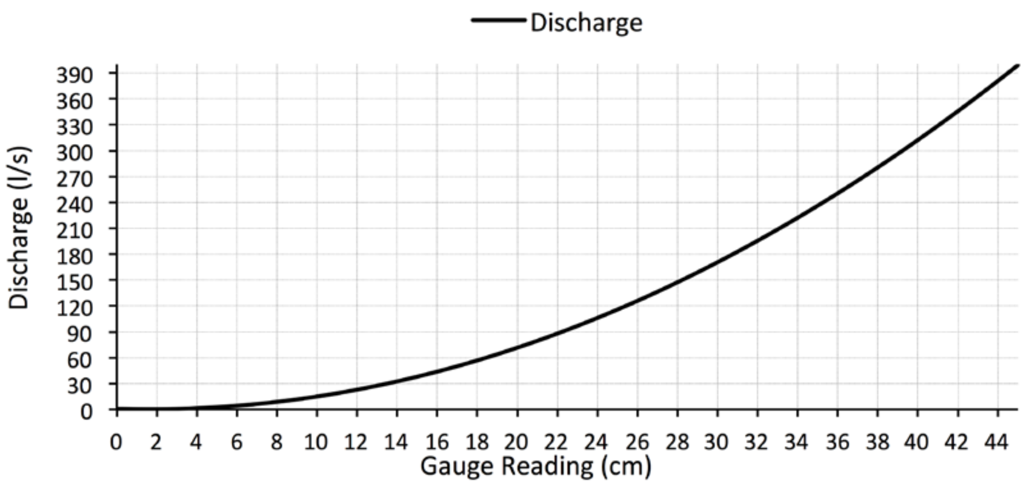
The weirs in the main and secondary canals are calibrated and their rating curves are generated for farmers to record the discharges.

Figure 80: gauge station at the weir

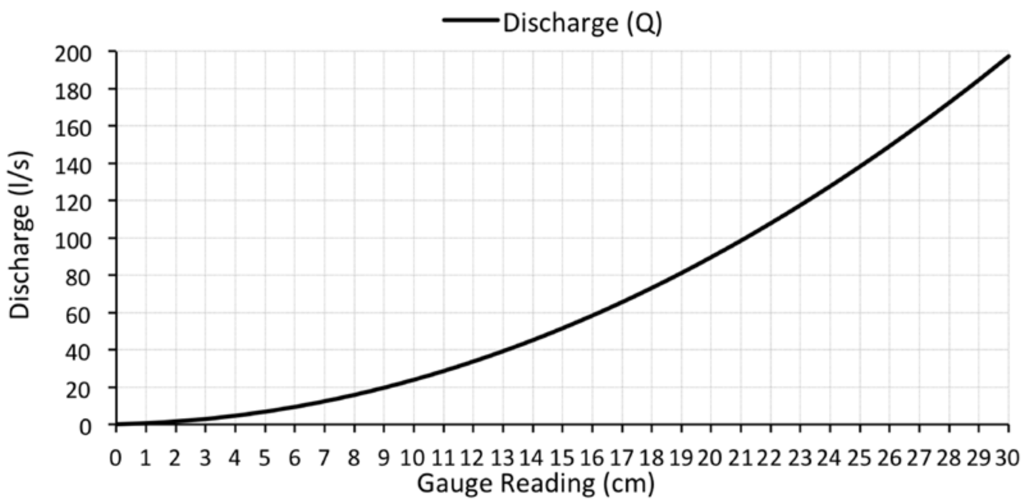
©FAO/Abdelouahid Fouial

By following discharge monitoring protocol, the overall water supply can be calculated during the irrigation season. The following rating curves are calibrated and validated through 3 irrigation campaigns. The rating curves can be read by matching the water level to the discharge.

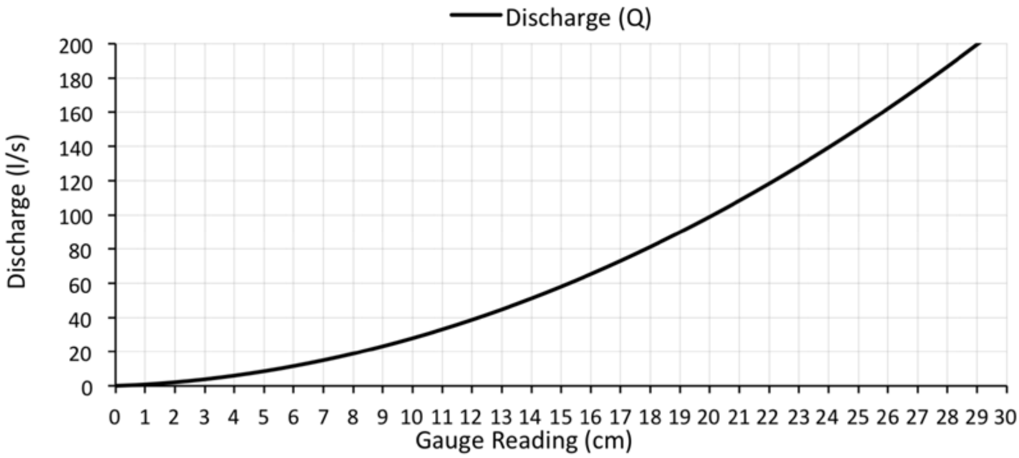
Main canal



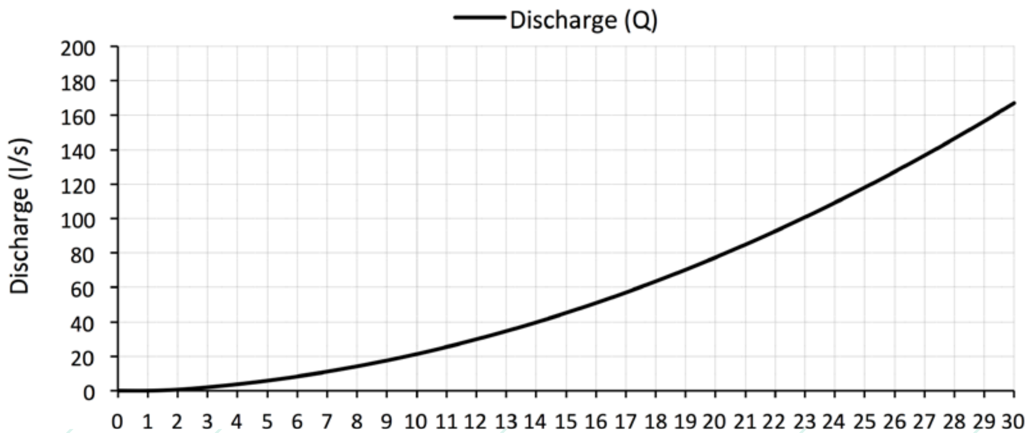
Division 8



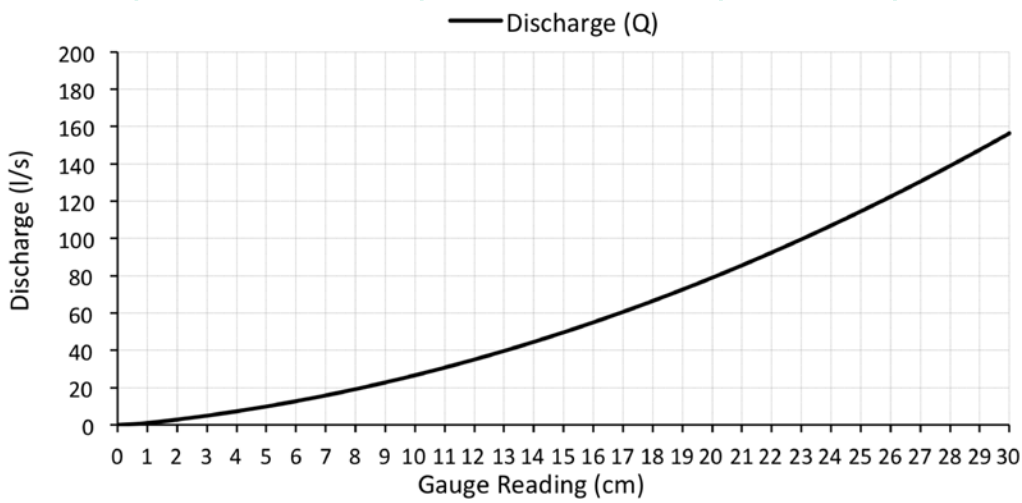
Division 9



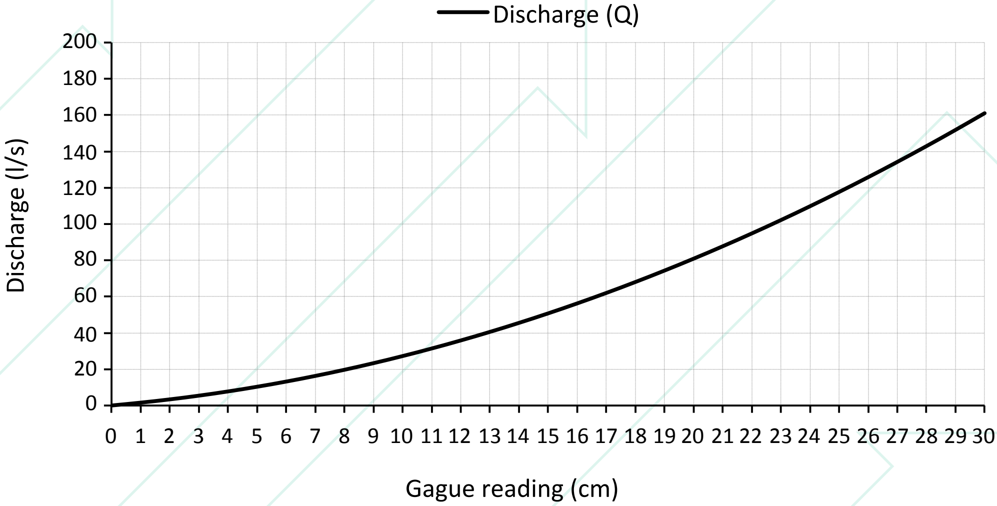
Division 10



Division 11

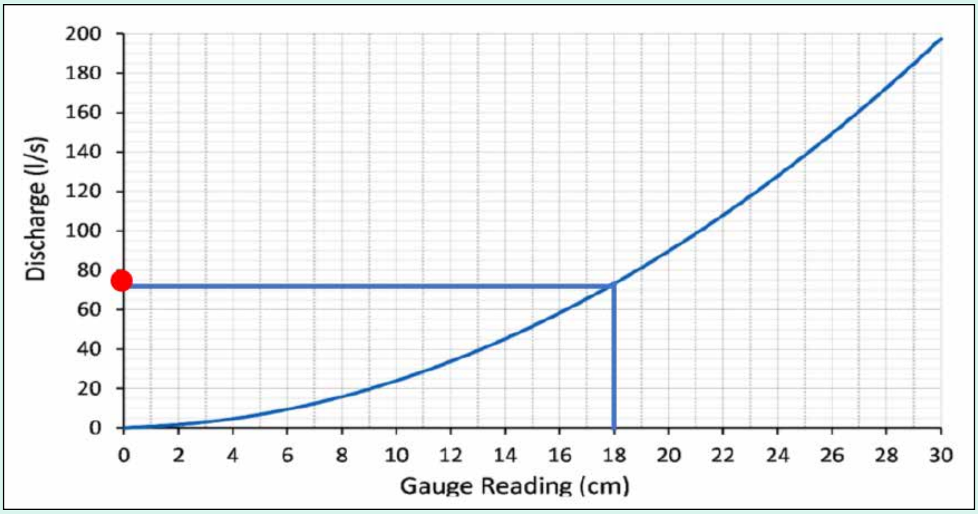


Division 12



Example of applying rating curve for matching demand with supply

If only one tertiary canal per time irrigates, supplying two farms (6.4 ha), the farmers can use the rating curve of the Division to calculate the discharge. Accurate data can be obtained by reading the water level and calculating the related discharge. If the irrigation turn lasts 8 hours at 18 cm water level, the related discharge is 78 l/s.



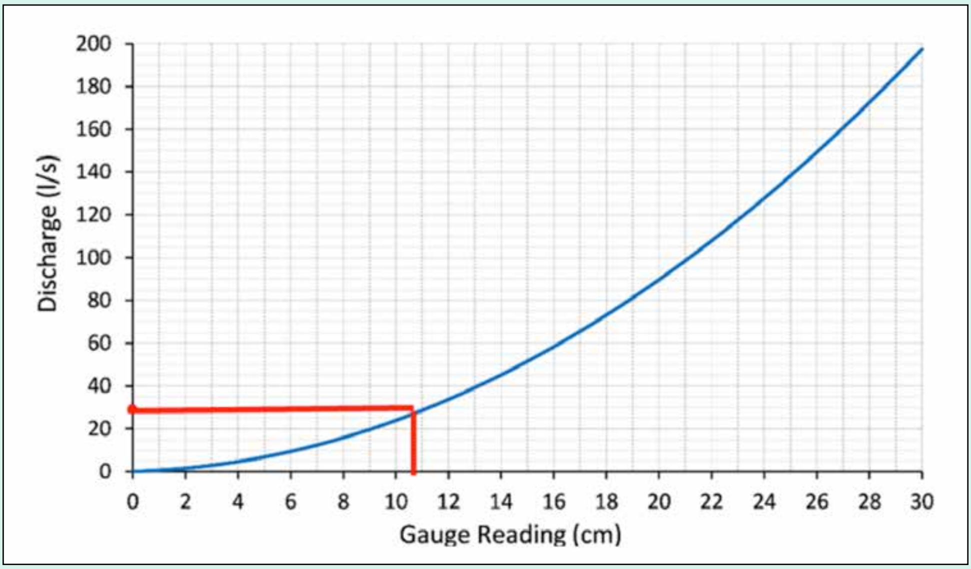
78 l/s during 8 hours → 78 l * 60 seconds * 60 minutes * 8 hours = 2 246 400 l = 2 246 m3 water supply per irrigation turn

The water supply must be corrected with the estimated Water use efficiency based on the factors explained in previous sections:

- Due to wind and high temperature, part of the water evaporates without reaching the fields → evaporation losses
- The soil is clay, so its permeability is considered low → negligible amount of deep percolation losses
- The velocity is high and the discharge exceeds the design discharge of the tertiary canal → large amount of runoff
- The entry phase of the tertiary canals are widened, so waterlogging occurs → runoff losses

Considering the identified problems above, the overall efficiency of the conveyance system is 60 percent. Correcting the overall daily water supply by the efficiency, the calculated effective water supply applied on the farms is 1 347 m3 in an irrigation turn for 6.4 ha.

If the tertiary canal irrigates twice a week during a 3 months long irrigation season, the total water supply for 6.4 ha is 32 328 m3 = 5 051 m3.



In conclusion, the 78 l/s discharge (18 cm water level) is still too high for efficient irrigation. In order to reach 3 200 m3 optimal irrigation water supply for 6.4 ha with an irrigation turn of 8 hours per day, farmers should keep 29-30 l/s discharge in the tertiary canals.

Annex: Unit conversion table

Length

1 inch (in) 0.0254 m

1 foot (ft) 0.3048 m

1 yard (yd) 0.9144 m

1 mile 1609.344 m

1 metre (m) 39.37 inches (in)

1 metre (m) 3.28 feet (ft)

1 metre (m) 1.094 yards (yd)

1 kilometre (km) 0.62 miles

Area

1 square inch (in2) 6.4516 x 10–2 m^2

1 square foot (ft2) 0.0929 m^2

1 square yard (yd2) 0.8361 m^2

1 acre 4046.86 m^2

1 acre 0.4046 ha

1 square centimetre (cm^2) 0.155 square inches (in2)

1 square metre (m^2) 10.76 square feet (ft2)

1 square metre (m^2) 1.196 square yard (yd2)

1 square metre (m^2) 0.00024 acres

1 hectare (ha) 2.47 acres

Volume

1 cubic inch (in3) 1.6387 x 10–5 m^3

1 cubic foot (ft3) 0.0283 m^3

1 cubic yard (yd3) 0.7646 m^3

1 cubic centimetre (cm^3) 0.061 cubic inches (in3)

1 cubic metre (m^3) 35.315 cubic feet (ft3)

1 cubic metre (m^3) 1.308 cubic yards (yd3)

1 cubic metre per sec (m^3/s) 1000 liter per sec (l/s)

1 cubic metre (m^3) 0.1 mm

Capacity

1. imperial gallon 0.0045 m^3

1. US gallon 0.0037 m^3

1. imperial barrel 0.1639 m^3

1. US. barrel 0.1190 m^3

1 pint 0.5681 l

1 US gallon (dry) 0.0044 m^3

1 litre (l) 0.22 imp. gallon

1 litre (l) 0.264 U.S. gallon

1 litre (l) 0.0061 imperial barrel

1 hectolitre (hl) 100 litres

= 0.61 imperial barrel

= 0.84 US barrel

1 litre (l) 1.760 pints

1 cubic metre of water (m^3) 1000 l

= 227 U.S. gallon (dry)

1 imperial barrel 164 litres

Mass

1 ounce 28.3286 g

1 pound 0.4535 kg

1 long ton 1016.05 kg

1 short ton 907.185 kg

1 gram (g) 0.0353 ounces (oz)

1 kilogram (kg) 1000 g = 2.20462 pounds

1 ton 1000 kg = 0.984 long ton

= 1.102 short ton

Pressure

1 pound force/in2 6894.76 N/m^2

1 pound force/in2 51.7 mm Hg

1 Pascal (PA) 1 N/m^2

= 0.000145 pound force /in2

1 atmosphere 760 mm Hg

= 14.7 pound force/in2

(lbf/in2)

1 atmosphere 1 bar

1 bar 10 metres

1 bar 100 kpa

Energy

1 B.t.u. 1055.966 J

1 foot pound-force 1.3559 J

1 B.t.u. 0.25188 Kcalorie

1 B.t.u. 0.0002930 KWh

1 Joule (J) 0.000947 B.t.u.

1 Joule (J) 0.7375 foot pound-force (ft.lbf)

1 kilocalorie (Kcal) 4185.5 J = 3.97 B.t.u.

1 kilowatte-hour (kWh) 3600000 J = 3412 B.t.u.

Power

1 Joule/sec 0.7376 foot pound/sec

1 foot pound/sec 1.3557 watt

1 cheval-vapor 0.9861 hp

1 Kcal/h 0.001162 kW

1 watt (W) 1 Joule/sec

= 0.7376 foot pound/sec (ft lbf/s)

1 horsepower (hp) 745.7 watt 550 ft lbf/s

1 horsepower (hp) 1.014 cheval-vapor (ch)

1 kilowatt (kW) 860 Kcal/h

= 1.34 horsepower

Temperature

0C (Celsius or centigrade-degree) 0C = 5/9 x (0F - 32)

0F (Fahrenheit degree) 0F = 1.8 x 0C + 0F

K (Kelvin) K = 0C + 273.15

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Field guide to improve water use efficiency in small-scale agriculture

The case of Burkina Faso, Morocco and Uganda

The role of irrigation in gearing agriculture development towards a broader economic growth is undeniable. Accordingly, irrigation is growing into key operational strategy for governments and their agencies to increase agricultural productivity, thus combatting food insecurity and boosting overall growth. While agriculture absorbs rural workforce, generates income and increases food security, it has become the most important driver in freshwater exploitation. The rapid expansion of water demand leads to the generalized phenomena of imbalance between water supply and water demand. This increasing pressure on water resources urges enhancing water use efficiency. Enhancing water use efficiency requires actions at all levels, from agricultural practitioners to scheme managers, and up to the policy-makers.

The objective of this field guide is to show practical measures to improve water use efficiency in small-scale agriculture based on case studies from Burkina Faso, Morocco and Uganda. The book not only presents applicable Water Use Efficiency measures, but also guide the readers through their real-term implementation.

While the guide provides complete set of instructions to improve water use efficiency in order to reach optimal irrigation practices, the successful outcome still depends on the farmers' willingness to embrace and adopt the recommended measures. The Guide holds in evidence that farmers are often constrained by available resources to improve their practices in terms of budget, inputs or labour. In order to take these issues into account, the recommendations are limited on practical measures, which can be followed by farmers without requiring additional resources.

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