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Guidance on realizing real water savings with crop water productivity interventions

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Executive summary

This technical document contains clear and practical guidelines on how to implement ‘real’ water savings in agriculture through interventions for enhancing crop water productivity. A distinction is made between real water savings and ‘apparent’ water savings. Apparent water savings record reductions in water withdrawals but do not account for changes in water consumption. Real water savings record reductions in water consumption and non-recoverable return flows (runoff or percolation). This guidance document emphasizes the paradox of water savings at field and basin scales, which usually do not translate into increased water availability for other users as is commonly believed.

An intervention framework groups water savings interventions into three categories: water management; soil and land management; and agronomy. An inventory of publications lists information on each intervention in terms of changes of the application of irrigation water, water consumption (i.e. evapotranspiration), crop yield, and water productivity. The best interventions for achieving higher water productivity mostly relate to agronomic practices. Reductions in water consumption (evapotranspiration) are achieved through selected agronomic and water management practices.

Realizing real water savings is context-specific. This guidance document provides information on the expected changes at field scale resulting from various interventions. The impact in a larger context requires analysis at district level or basin scale. The ‘follow the water’ concept introduces water accounting terms to communicate the categories of water flows in a system. ‘Water saved,’ for example, is the amount of water resulting from reducing consumption and/or the non-recoverable fraction of the return flows that can be made available for alternative uses. Following the concepts and guidelines in this document, decision-makers can improve the management of their water systems by introducing sustainable interventions to achieve real water savings.

1. Introduction

1.1 OBJECTIVE

This report aims to provide clear and practical guidelines on how to implement 'real' water savings in agriculture by selecting suitable interventions that enhance crop water productivity. A distinction is made between real water savings and 'apparent' water savings. Apparent water savings record reduced water withdrawals but do not account for changes in water consumption; this is commonly used as the definition for water saved through interventions. Real water savings record reductions in water consumption and non-recoverable return flows (runoff or percolation).

This report emphasizes the paradox of water savings at field and basin scales, which usually do not translate into increased water availability for other users. It offers water savings options that can help agriculture become more productive without increasing water consumption. The background and concepts are explained in Chapter 2. Crop and water management interventions are described in Chapter 3, including an intervention framework. Chapter 4 provides a summary of the inventory reference database, including the impact of water savings interventions on water consumption and crop production. Chapter 5 provides detailed descriptions of the various water savings interventions.

1.2 AUDIENCE

This guidance document targets audiences ranging from extension services officers to water managers and irrigation specialists, who design and manage irrigation systems, and policymakers or river basin planners, who make decisions on the allocation of water resources.

1.3 RELEVANCE

Increased water use has led to water scarcity in many Asian countries. This trend will continue: the gap between water demand and supply is projected to increase due to population growth and economic development (Dinar *et al*., 2019) as well as environmental factors, such as land degradation (IPCC, 2019) and climate change (Turral *et al*., 2011). Efforts to reverse these trends should focus on irrigated agriculture, since irrigation is the largest consumer of freshwater withdrawals in almost all water-scarce regions. The Food and Agriculture Organization of the United Nations (FAO) has played a leading role in finding agricultural solutions to managing water shortages.

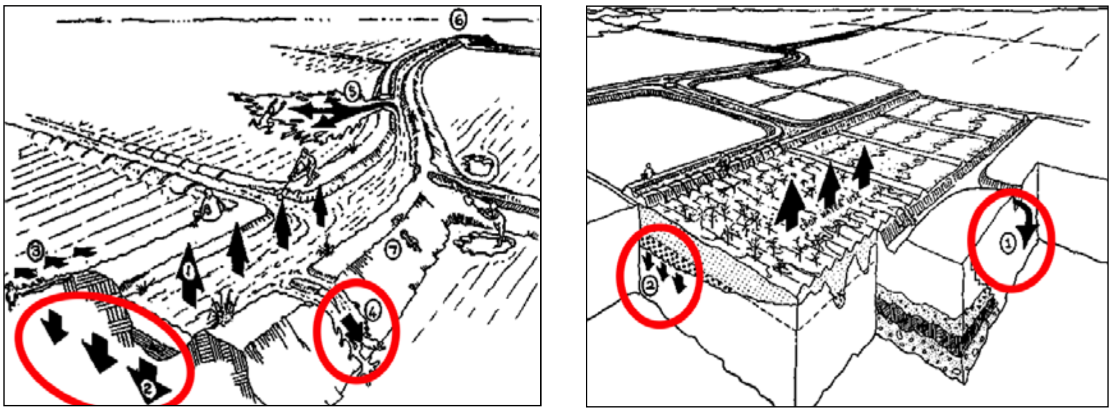
Unfortunately, overcoming the water crisis through agricultural interventions is not simple and has often led to unrealistic expectations. Recent decades attention has been brought to the misconceptions and overly simplistic (and often erroneous) views in agricultural water management. However, the uptake of these warnings by decision-makers and the irrigation sector has been limited for various reasons. For example, decision-makers rarely have sufficient information on which to base their determinations. The availability of measured observations on real water savings requires extensive data collection. Frequently, the interest of key players is bound to certain scales i.e. the field scale for farmers and basin scale for river authorities. This could make it difficult to find a common goal and language. A significant issue is that the modernization of irrigation systems has, in many cases, increased water consumption, rather than create the water savings that are often assumed to be delivered by irrigation modernization programmes (Adamson and Loch, 2014; Pérez-Blanco *et al*., 2020; Perry and Steduto, 2017; Ward and Pulido-Velazquez, 2008) Concepts such as irrigation in the basin context and water accounting have shown that water savings at the basin scale are in reality often limited and that water consumption may even increase (Giordano *et al*., 2017)(Giordano *et al*., 2017).

FAO's Regional office Asia and Pacific (RAP) Water Scarcity Programme aims to develop a suite of tools, guidance documents and policy dialogue processes to assist countries to improve water productivity in the face of scarcity and to prepare the agriculture sector for a productive future with less water. The proposed approach is appropriate in that it deliberately and systematically combines technical and data analysis with policy and governance reform and capacity development, the latter being a difficult task that generally receives less attention and investment.

2. Background and concepts on real water savings

It is commonly perceived that large quantities of water are wasted during the irrigation process and that real water savings could reduce the need for facilities to extract more water (Molden *et al.*, 2001). This perception is derived from common knowledge that on-farm irrigation efficiencies are often in the order of 20 to 50 percent, implying that the remaining 80 to 50 percent of the water withdrawn is somehow lost. Typical examples of this thinking have been reflected in various FAO publications over the past 30 years (see Figure 1).

FIGURE 1
Last century perspectives on water losses. Irrigation water losses in canals (left) and irrigation water losses in the field (right) to groundwater or surface runoff.



Source: FAO (1989a, 1989b)

The chief misconception stems from the classical notion of 'irrigation efficiency' as developed in irrigation engineering. Irrigation efficiency is commonly measured as the ratio of water consumed to water applied or withdrawn from a source. But applying this concept to water basins could lead to incorrect decisions and therefore to faulty public policy (Keller and Keller, 1995). The authors observe:

"This classical efficiency concepts do not account for return flows and their subsequent reuse. Thus, applying irrigation efficiency concepts alone could lead to the conclusion that significant opportunities existed for efficiency gains. In reality, however, despite local irrigation inefficiencies, the scope for improved efficiency at the sub-basin or basin scale (and thus for real water savings) is limited due to the reuse of the return flows elsewhere. Moreover, because of the opportunity to recharge groundwater aquifers through return flows, a strategy involving overwatering on the fields and allowing seepage losses from conveyance canals may be preferable to promoting local (application or conveyance) efficiency gains."

BOX 1

'Follow the Water' Terminology

Water use is the amount of water employed for a specific purpose (e.g., irrigation, energy, industrial process, domestic washing, etc.).

Water can be consumed, returned to the system where it has been employed or stored.

The consumption of water can be either beneficial (e.g. crop transpiration) or non-beneficial (e.g. soil evaporation).

Water that is returned to the system (return flows) is either recoverable (e.g. returned to a river or an aquifer) or non-recoverable (flowing to the sea, polluted, or returned to economically unviable sinks).

Water saved is the amount of water resulting from a reduction in consumption and/or in the non-recoverable fraction of the return flows that can be made available for alternative uses.

Water saving refers to the technologies, practices and measures (here called interventions) that result in the reduction in consumption and/or in non-recoverable fraction.

The scientific interest in real water savings is growing rapidly and, along with it, the quantity of journal articles, expert reports and conferences. The term 'real water savings' emphasizes the need to broaden our perspective from the field to the entire basin. In other words, we need to understand real water savings as an intervention that releases an identified quantity of water to an alternative use. A recent review (Pérez-Blanco *et al*., 2020) observed that the number of case studies on the performance of water conservation technologies beyond the field scale has increased significantly in recent years: out of 224 applied case studies on this topic over a period of 42 years (1976-2017), some 91 (40.6 percent) were published in the last nine years (2010-2018). -

Box 1 defines the key concepts used in this publication.

The siloed worlds of the water and agriculture/agronomy sectors have contributed to the misconceptions around irrigation and water wastage. Further integrating the two sectors could potentially lead to real water savings and/or increased water productivity. Typical examples of the interface between water management and agronomical practice, where potential water productivity improvements can be made, are mulching, deficit irrigation at specific times, planting density, weed control, fertilizer, cultivar selection, growth enhancers (polyamines: putrescine, spermidine), tillage practices and terracing, among others.

A second important aspect of water savings is the relationship between crop evapotranspiration and yield. It is reported that yield is linear in relation to crop transpiration under the conditional constraint of "everything else being equal (Perry and Steduto, 2017)." Many options for real water savings exist, particularly in Asia with its wide diversity of irrigation practices, crops and crop management approaches.

According to Perry and Steduto (2017):

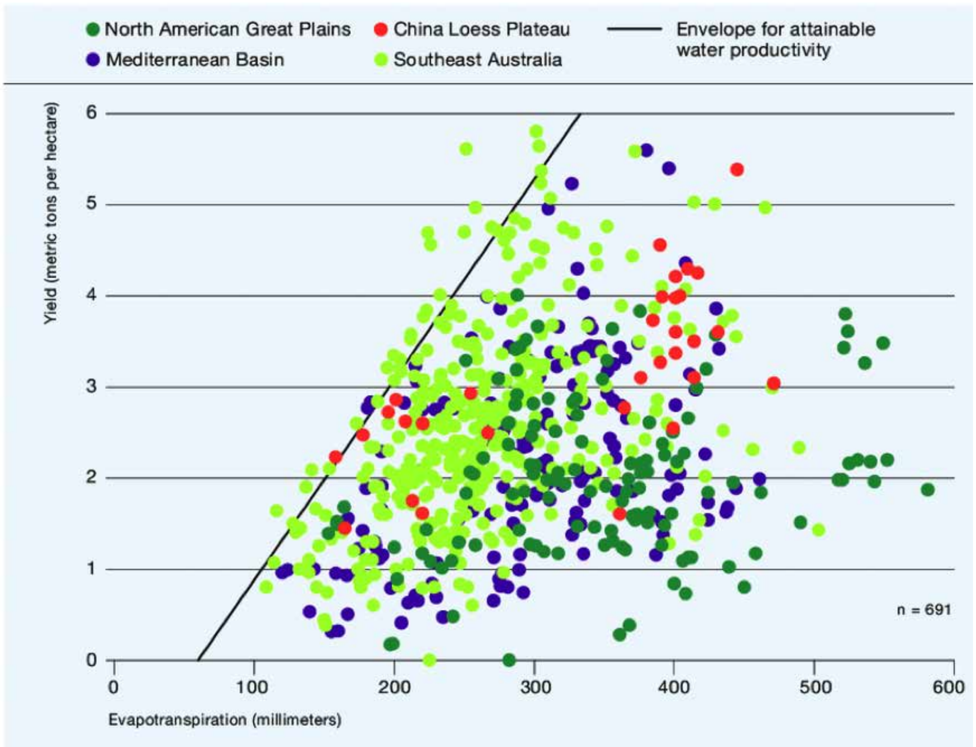
"When field data are collected from a large number of farmers, some farmers achieve substantially higher yields for the same level of crop transpiration than other farmers. A common interpretation of this observation is that better management of water and other agronomic inputs/practices could capture this increment and overall production could be raised for the same level of water consumption (or water could be 'saved' while production is maintained)."

The authors note that the near linear relationship between yield and crop transpiration is "derived for a specified and consistent package of crop husbandry (planting date, cultivar, planting density, fertilization status, soil, etc.) with only water input being varied." In other words, if water is limited, simply increasing the supply will increase production (kg) but will not increase productivity (kg/m^3). Productivity increases (which provide the basis for real water savings) will usually depend on changes to other aspects of the farmer's practices that focus on the water-agronomy aspects where real water savings are possible or where higher production can be achieved with the same amount of evapotranspiration.

Non-linearity between crop evapotranspiration and yield can be substantial, however, given the wide-range of climate, agro-economic zone and farm management practices.

Figure 2 shows that ranges in yields can differ by a factor of five with the same amount of evapotranspiration. Box 2 elaborates further on the connection between water savings interventions and water productivity.

FIGURE 2
Variations in the water productivity of wheat (kg/ha/ET) in different regions



Source: Giordano et al. (2017)

BOX 2

Does increased water productivity save water?

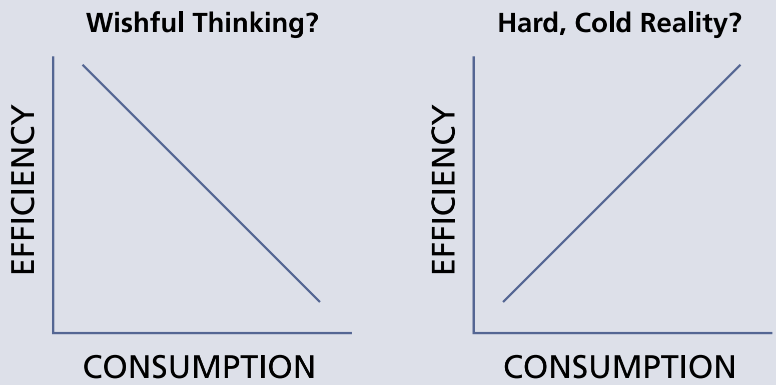
Interventions that increase water productivity (the water consumed in producing a crop) are frequently assumed to save water, on the grounds that the same quantity of crop can be produced with less water. This assumption is true if the water allocation is reduced when the intervention is introduced. However, in practice, effective and enforceable water allocation systems frequently do not yet exist in developing countries.

The parallel case of increasing land productivity (kg/ha) is more easily understood. if a farmer can grow 20 percent more crop per hectare with a new variety, we do not expect him to automatically reduce the cropped area.

In fact, an increase in water productivity frequently has the perverse effect of increasing demand for water: the farmer can afford to pump more water from a deeper well if the productivity of that water increases.

The impact is intensified when drip irrigation is introduced: the technology results in an increase in water consumption per unit of water pumped and an increase in the productivity of the pumped water. Physical consumption increases as does economic demand.

This effect is often referred to as the rebound effect or 'Jevon's Paradox'. As the graphs below show, with technological interventions that improve efficiency or water productivity, it is expected that water consumption decreases. In reality, it is possible that water consumption increases.



In addition to the paradigm shift in agricultural water management from a local irrigation efficiency perspective to basin scale assessments, water saving is another important consideration. It may seem obvious that water saving is generally considered positive, but what happens to the saved water and at which scales (temporal and spatial) should the saving be assessed?

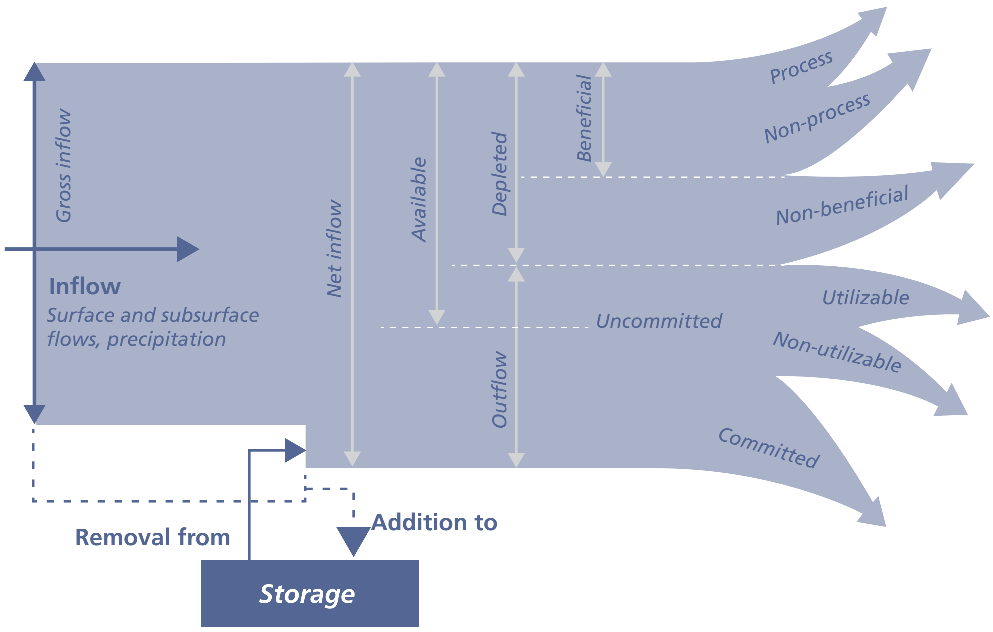
Perry (2020, personal communication) proposes the following definition for water saving:

"Water saving is an intervention that results in incremental water being made available for an alternative beneficial use, including but not limited to environmental services or stabilizing an aquifer."

In other words, if there is no alternative beneficial use, actions to save water are probably not needed. One could add to Perry's definition that the alternative beneficial use should have a higher priority and/or higher water productivity than the original use. Priority is often determined by decision-making processes allocating water for different sectors (e.g. agriculture versus environment), while water productivity is generally used to compare use within one sector (e.g. irrigated vegetables versus irrigated rice). Extensive research and literature are available on water productivity (expressed as kg per cubic meter water consumption, or USD per cubic metre water consumption).

Moving from an on-farm to a basin perspective, it is often found that because 'lost' water is often reused, far less water is lost than commonly perceived. From a hydrology perspective, this is common knowledge and is referred to as the water cycle: water is never lost because evaporated water will precipitate elsewhere as rain or snow. In irrigation science, this concept started around 2000. It is often referred to as water accounting, which focuses on withdrawal and return flows within a basin context. A typical example of this approach is shown in Figure 3.

FIGURE 3
Water accounting framework for irrigated agriculture



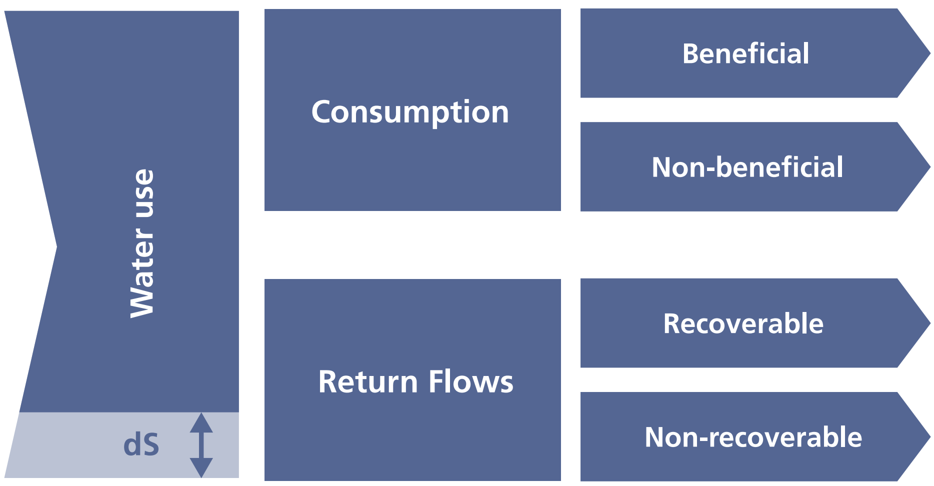
Source: Molden et al. (2001)

Many efforts have been made to improve and enhance water accounting frameworks. These efforts have introduced refinements that add an additional level of complexity but often lack the data needed to make them useful. Moreover, the complexity of the frameworks has made it difficult for decision-makers and non-specialists to grasp the main message: water is never lost. Following internal discussions, the International Commission on Irrigation and Drainage adopted a simplified approach focusing on four main components of water flows. This simplified approach was summarized by Perry (2007) to ensure that focus would be on the main components of those water flows. Our report uses this approach – known as 'follow the water' – which is outlined in Figure 4. The main concept is that water diverted to irrigation schemes can be divided into the following components:

- The consumed fraction (essentially evapotranspiration), comprising:
  - beneficial consumption (for the purpose intended or another beneficial use);
  - non-beneficial consumption (such as by weeds, evaporation from wetted surfaces, or capillary rise during a fallow period);
- The non-consumed fraction, comprising:
  - recoverable flows (water flowing to drains and back into the river system for possible diversion downstream, and percolation to freshwater aquifers);
  - non-recoverable flows (percolation to saline aquifers, outflow to drains that have no downstream diversions or direct outflow to the ocean).

The inventory of water savings techniques described in Chapter 4 and the guidelines for practical intervention in Chapter 3 are based on the follow the water approach.

FIGURE 4
Simplified water accounting system known as follow the water, with dS representing delta (i.e. change) of water stored.



3. Crop and water management options in irrigated agriculture

3.1 INTRODUCTION

The necessity to improve crop and water management has been highlighted in many studies and reports. However, most of these limit themselves to emphasizing the importance of optimizing crop and water management without actually providing guidelines on how to do so. Indeed, the scientific literature includes many detailed studies on rather small and location-specific components of optimizing crop and water management. Another challenge is to develop a structured framework that allows broader options to be broken down into smaller ones. No universal categorization of interventions exists as this depends on the overall objective. A number of options relevant to crop and water management are summarized below.

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An FAO study on adaptation to climate change (Turral *et al.*, 2011) includes an interesting framework for improving crop and water management.

The framework consists of the following elements:

- On-farm management
  - crop selection and crop calendar
  - farm and crop management – fertilizer management
  - water management on farm
  - irrigation technologies on farm
  - depletion accounting
  - flood protection and erosion
  - commercial agriculture.
- Adaptation at irrigation system level
  - water allocation
  - system performance
  - cropping patterns and calendars
  - conjunctive use of surface water and groundwater
  - irrigation policy measures.
- Adaptation at river basin and national levels
  - irrigation sector policy
  - coping with droughts
  - coping with flooding – structural and non-structural interventions

  - managing aquifer recharge
  - assessment of adaptation options to ensure irrigation supply security.
- Adaptive capacity in agricultural water management – policies, institutions and the structure of the subsector
  - mechanisms for allocation
  - national food policy issues.
- Institutions
- Long-term investment implications for agricultural water management

The report concludes that, for irrigated agriculture specifically, the options at farm level can be considered in the following terms:

1. manipulation of crop selection and the cropping calendar;
2. better management of factor inputs – nitrogen and agricultural chemicals;
3. improved water management technologies and techniques for cropping.

Aerts and Droogers, 2004

Similarly, Aerts and Droogers (2004)until now clear guidance on how to respond to this challenge, particularly at the river basin level, has been lacking.This book has been developed from the ADAPT project, focusing on the development of regional adaptation strategies for water, food and the environment in river basins across the world. A generic methodology is presented and applied to seven case studies in contrasting geographical areas of the world: Mekong (SE Asia report that two main groups of options at the farm level should focus on:

1. improved farm management;
2. crop production technology.

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An FAO report, *Coping with water scarcity: an action framework for agriculture and food security* (FAO, 2012) made it very clear that changes are needed in water policy concerning:

- Managing supply
  - increased storage
  - groundwater development
  - recycling and re-use
  - pollution control
  - inter-basin transfer
  - desalination.

- Managing demand
  - re-allocation
  - increased efficiency of use.

In terms of agricultural policy, the report described the following options:

- supply enhancement
- water recycling and re-use in irrigation
- reducing water losses[1]
- improving crop water productivity
- re-allocating water from lower to higher-value use in irrigation.

TABLE 1
Water scarcity response options by major policy domain

Major policy domain	Supply enhancement	Demand management
Water	River diversion; dams; groundwater development; desalinization; pollution control	Intersectoral allocation; increase in the overall efficiency of sectoral water use
Agriculture	On-farm storage; groundwater development; re-use and recycling	Increase in crop productivity; reduction in losses; restraining the cropped area under irrigation; intrasectoral allocation (shifting to higher value production)
National food security	Food imports, storage, distribution efficiency	Reduction in waste in the food chain; changes in dietary habits

Source: FAO, 2012

Perry *et al.*, 2009

The landmark[2] paper by Perry, Steduto, Allen and Burt is concerned with increasing productivity in irrigated agriculture. Although the study focuses mainly on putting the terminology and thinking about water savings into a proper perspective, it also discusses the crop and water management options that are available to farmers. The paper argues that there is no simple answer to the question of which irrigation method is best. Moreover, the authors emphasize that "irrigation technology is often a farm-level choice, and it is appropriate to consider the farmer's perspective carefully in understanding options and impacts (Perry *et al.*, 2009)." The choices made by farmers depend on:

- *Increased income*. Farmers will have an incentive to improve if yield quantity, quality, or alternative high-value crops will more than adequately reward the investment.

1 The report emphasizes that it is now widely accepted that, while irrigation losses appear high, a large part of these 'losses' are return flows or aquifer recharge, which can be tapped by other users further downstream.

2 152 citations according to Science Direct (December 2019)

- *Risk aversion/food security*. Farmers may shift from rainfed agriculture to irrigation to reduce the uncertainties associated with variable rainfall patterns. Similarly, they may shift from public surface water delivery systems to well water because surface water is delivered in an inflexible and unreliable manner.
- *Convenience*. This is primarily seen in commercial farming. For example, a farmer may not want to have to wake up in the middle of the night to receive water deliveries or he may be able to deliver fertilizers more precisely and cheaply through 'fertigation'[3] systems.
- *Reduced costs*. A farmer may save on pumping costs if delivery losses are reduced; he may save on labour by installing equipment that does not require a constant field presence.
- *Non-water related motivations*. These include saving on labour, growing higher-value crops, reducing uncertainty, cost, credit availability, extension advice, technical support and land levelling, among others.

The Asia Pacific Adaptation Network (APAN)[4]

APAN has developed an Adaptation Technology Database that defines ten categories, each of which has a subset of technologies. Relevant categories are:

- capacity building and stakeholder organization
- crop improvement
- cropping techniques
- erosion control
- processing techniques
- soil management
- storage options
- sustainable crop management
- urban agriculture.

The total number of technologies is limited and it is unlikely that the database is still current (the last update was in 2015). The approach is quite interesting, however, as each of the technologies has the following descriptors:

- technological maturity
- applicable immediately
- technology owners
- cost
- ease of maintenance
- technology performance

[3] Fertigation is the practice of injecting fertilizers in the irrigation water.

[4] http://www.asiapacificadapt.net/adaptation-technologies/database

- co-benefits,
- suitability for developing countries.

The Asian Development Bank (ADB), 2020

A so-called 'good practice guide' for supporting adaptation decision-making for climate-resilient investments in the water sector (Droogers and Carpenter, 2020) includes some interesting criteria for evaluating various adaptations. Although the criteria are specifically focused on climate change adaptations, some are relevant to our purposes:

- Time – implementation period and longevity of intervention
  - short, medium, long
- Effectiveness – extent to which vulnerability is reduced
  - contributes, partial, total
- Relative cost – compared to other options or business-as-usual
  - low, medium, high
- Co-benefits – beyond resilience e.g. carbon sequestration, job creation
  - limited, medium, high
- Barriers to implementation – degree of complexity, e.g. multi-country agreements
  - easy, medium, difficult
- Capacity required to implement – extent of specific e.g. technical, legal, data requirements
  - simple, medium, advanced
- Scale of implementation – areal extent of benefit from adaptation measure
  - local, regional, national, international
- Applicable locations and conditions – extent of geographical limitations
  - specific, many, universal

Pérez-Blanco *et al.*, 2020

This study examined 230 empirical and theoretical papers on water conservation technologies (WCTs). The review concluded that WCTs should not be regarded as simply a way to achieve water conservation, but also as a means to stabilize and enhance agricultural water productivity and farmers' income where water is scarce.

The study makes a strong distinction between WCTs and WCPs (water conservation policies) and argues that if the goal is water conservation (real water savings) to effectively increase the quantity of water available for other uses, appropriate policies are an essential complement to new technologies.

In preparing this guidance document, the 230 interventions reported by Pérez-Blanco *et al*. were further examined, filtered and categorized (Table 2). Many of the technologies had an objective to achieve 'increased efficiency' as a means of saving water, but in most cases, this related only to field-scale level reductions in water applications.

Interestingly, this study hardly addresses agronomic aspects of WCTs and is limited to two categories of interventions: 'alternate wetting and drying' and 'deficit irrigation.' Perry and Steduto (2017) explain the importance of including agronomy technologies in such reviews:

- When field data are collected from a large number of farmers, some farmers achieve substantially higher yields for the same level of crop transpiration than other farmers.
- A common interpretation of this observation is that better management of water and other agronomic inputs/practices could capture this increment and overall production could be raised for the same level of water consumption (or water could be 'saved' while production is maintained).
- The near linear relationship between yield and crop transpiration is derived for a specified and consistent package of crop husbandry (planting date, cultivar, planting density, fertilization status, soil, etc.) with only the water input being varied.

TABLE 2
Overview of the WCT's (water conservation technologies)

Technology	Number
Increase efficiency	91
Pressurized	52
Multiple	30
Micro-irrigation technologies	21
Other	8
Zero tillage	7
Alternate wetting and drying	5
Canal lining	5
Scheduling	4
Rainwater harvesting	3
Deficit irrigation	2
Land levelling	1
Mulching	1
Total	230

Source: Pérez-Blanco et al. (2020)

IWMI Research Report 169

The International Water Management Institute (IWMI) initiated a rethinking of irrigation water efficiencies: "The new era of water resources management: From 'dry' to 'wet' water savings.'" IWMI Research Report 169 (Giordano *et al*., 2017) outlines several key ideas that fundamentally changed the research paradigm from a focus on irrigation efficiency and the performance of irrigation systems to one centred on water productivity and river basin management.

The report describes a framework for achieving real water savings. It defines four main intervention groups, providing examples for each:

- Increase yield per unit of water consumed by, for example:
  - improving water management by better timing water supplies to reduce stress at critical crop growth stages or by increasing the reliability of supplies to enable farmers to invest more in other agricultural inputs;
  - improving non-water inputs that increase production per unit of water consumed, and agronomic practices, such as laser land levelling and fertilization; and
  - changing to new or different crop varieties with higher yield per unit of water consumed.
- Reduce non-beneficial depletion by, for example:
  - increasing the proportion of water applied that is used beneficially by crops, by: i) reducing evaporation from water applied to irrigated fields through more capital intensive technologies (such as drip irrigation) or better agronomic practices (such as mulching or changing crop planting dates to match periods of less evaporative demand); and ii) restricting evaporation from bare soil through conservation agriculture (such as land levelling or zero tillage);
  - lessening evapotranspiration from fallow land by reducing the area of free water surfaces, decreasing non-beneficial or less beneficial vegetation, and controlling weeds;
  - reducing water flows to sinks by decreasing irrecoverable deep percolation and surface runoff by such measures as canal lining and precision irrigation;
  - minimizing salinization (or pollution) of recoverable return flows by minimizing flows through saline (or polluted) soils and groundwater; and
  - shunting polluted water to sinks to avoid the need for dilution with water of usable quality.
- Tap uncommitted flows by, for example:
  - adding water storage facilities, including reservoirs, groundwater aquifers, tanks and ponds, on farmers' fields;
  - improving management of existing facilities to obtain more beneficial use of existing water supplies; and
  - reusing uncommitted return flows through gravity or pump diversions to increase irrigated area.

- Reallocate water among uses by, for example:
  - reallocating water from lower to higher-value uses within or between sectors while addressing possible effects on downstream uses.

3.2 INTERVENTION FRAMEWORK

The frameworks described in the previous section have been used to derive a practical hierarchal setup for the interventions described in this guidance note. The setup is simple and consists of three levels: theme, category and intervention. Each intervention has the potential to enhance crop and water management. The term 'enhance' is used here because the overall aim is to increase water productivity at the basin scale and/or to reduce water consumption to support downstream water users.

The interventions described in this guidance note go beyond the traditional water/irrigation perspective, as it is clear that real water savings can more often be found in agronomy interventions rather than in water/irrigation interventions only.

Interventions for integrated or diversified farming systems are excluded from this framework. Examples of such systems are farms that integrate crop production with livestock and thus improve their economic productivity per unit land.

TABLE 3
Categorization of the interventions as used in this guidance document

Theme	Category	Intervention
Water	On-field irrigation methods	Border/furrow irrigation
		Sprinkler irrigation
		Drip irrigation
		Sub-surface irrigation
	On-field irrigation management	Supplemental irrigation
		Regulated deficit irrigation
		Surge irrigation
		Alternate wetting and drying
	Irrigation infrastructure	Canal lining
		Pipes
	Moisture recycling	Greenhouse
		Hydroponics
Soil and Land	Tillage Soil and Land	Zero tillage
		Tillage
	Land grading	Field levelling
		Terracing
		Block-end or soil bunds

Agronomy	Supplements	Fertilizers
		Growth enhancers
	Crop selection	Crop rotation
		Cultivars: high yields
		Cultivars: short duration
		Cultivars: rooting depth
		Timing of planting / sowing
		Planting density
	Coverage	Mulching
		Shading
		Weed control
		Cover crops
	Disease control	Pesticides
		Biological
	Salinity management	Leaching
		Salt-tolerant crop types

4. Inventory

The intervention framework presented in Section 3.2 of this document (Table 3) provides a structure for three themes – water, soil/land and agronomy – and the categories and interventions underlying each theme. Based on this framework, we conducted an inventory to quantify the impact of each intervention on water management and productivity. A literature review gathered results from peer-reviewed articles, technical documents and other publications. This chapter provides a summary of the inventory and our main findings.

4.1 INVENTORY DATABASE STRUCTURE

The list of references included in the inventory is provided in Annex 1. The inventory is based on the following structure.

Publication type

The literature used for compiling the inventory database consisted of peer-reviewed articles, technical documents and reports, working papers and conference papers.

Countries and climate zones

The literature review focused on countries in the Asia and Pacific region. Other countries were included whose climatic conditions are similar to those in the region, for example the Mediterranean and the western United States of America. Distinction was made between arid, temperate, tropical and continental climates, according to the Köppen climate classification.

Methodology

The methods and spatial scale applied in each study were noted (if reported). These varied from field experiments, farmers surveys, measurements of a block of fields and irrigation district (scheme) level, and simulation models at field, district and hydrological levels.

Reported changes

Publications were included that could indicate a change in water volume or crop production due to a particular intervention. These changes were quantified as percentages of change from the original condition (baseline). Changes were noted for the following aspects:

- irrigation or water applied;
- evapotranspiration or water consumption;
- return flow as runoff or drainage;
- crop yield;
- water productivity: yield per unit of evapotranspiration (water consumed);
- irrigation water productivity: yield per unit of irrigation (water applied).

4.2 SUMMARY OF INVENTORY FINDINGS

A summary of the inventory and reported changes is presented in Annex 2, indicating the average changes in percentages for the various interventions presented in 240 publications. These are also listed in Table 4, which indicates the number of publications reporting increases or decreases for irrigation, evapotranspiration (ET), crop yield and water productivity.

The publications reporting changes in irrigation fall mostly under the water theme. The studies examining the impact of drip irrigation report that the amount of irrigation water applied decreased in all cases. For evapotranspiration, more studies reported an increase in irrigation water than reported a decrease. Ultimately, crop yield increased in almost all studies of drip irrigation that included such information. As shown in Table 4, all of the studies show that regulated deficit irrigation caused ET to decrease. However, yield also decreased in almost all of the studies reporting on these aspects. Zero tillage and mulching are comparable interventions that use plant residue or other material to cover the bare soil. Both interventions promote a decrease in evapotranspiration and an increase in yield. These interventions also successfully increased water productivity. Water productivity also increased with the use of fertilizers. Other interventions are listed in Table 4 and are also summarized in Annex 2.

4.3 MOST AND LEAST SUCCESSFUL INTERVENTIONS

Table 5 lists the five most successful and the five least successful interventions for each irrigation, evapotranspiration, yield and water productivity. The anticipated success rate is independent of other factors, e.g. number of studies, crop type, irrigation method, climate zone and country, but is based on the average of all studies, as listed in Annex 2, excluding interventions with two or fewer publications in the inventory.

The top five interventions for reducing irrigation are all related to water management (in blue). Notably, regulated deficit irrigation results in a reduction in irrigation as well as evapotranspiration. However, deficit irrigation falls into the bottom five for crop yield and water productivity. The best interventions for achieving higher water productivity are mostly related to agronomic practices. Increases in yield can be achieved through both agronomic practices and water management interventions, namely subsurface irrigation and conversion to pipe irrigation distribution systems, rather than open canals. It should be noted that the pipe distribution system is an intervention implemented at a district (or subunit) level. This requires more investment and cooperation from farmers but can result in higher returns in crop yield. Crop rotation is one of the top five interventions for reducing evapotranspiration. However, it falls into the bottom five for both yield and water productivity. By changing the crop rotation, fewer crops are grown, which has a larger impact on yield than on reducing evapotranspiration, as indicated by water productivity.

The conclusion is that there are a range of management options that farmers can choose to improve their water productivity while protecting their incomes. Chapter 5 provides further detail on each intervention, including its to a particular spatial scale. The chapter also supplies practical guidance on implementing the interventions. Box 3 highlights the perspectives of decision-makers and possible incentives for farmers to implement specific interventions.

TABLE 4

Inventory summary of the number of publications reporting increases or decreases in irrigation, evapotranspiration (ET), crop yield and water productivity (WP) resulting from various field interventions

Theme	Category	Intervention	# of publications reporting an increase (↑) or decrease (↓)								# of publications
			Irrigation		ET		Yield		WP		
			↑	↓	↑	↓	↑	↓	↑	↓	
Water	On-field irrigation methods	Border/furrow irrigation		3							3
		Sprinkler irrigation	1	11			4	1			12
		Drip irrigation		47	16	7	41	2	1		67
		Sub-surface irrigation		4		1	4				6
	On-field irrigation management	Regulated deficit irrigation		7		15	3	24		1	27
		Surge irrigation		5						1	6
		Alternate wetting and drying		2			1	1	1	1	3
	Irrigation infrastructure	Canal lining		1		1	1				2
		Pipes		3	2	2	2				4
	Moisture recycling	Greenhouse		1		1	1		1		1
Soil and Land	Tillage	Zero tillage	1	9	2	5	13	2	6	3	25
		Tillage				1		1			1
	Land grading	Field levelling		10		3	13		1		14
Agronomy	Supplements	Fertilizers					4		9		12
	Crop selection	Crop rotation	1		1	2	1	3	1	1	4
		Cultivars: high yields			1	1	2		3		3
		Cultivars: short duration		1		1		1	3		3
		Cultivars: rooting depth						1			1
		Timing of planting/sowing		1		3	2	1	1	1	6
		Planting density			1		1		1		1
	Coverage	Mulching			3	20	12		12	1	24
	Other Interventions	Other (please specify)		9	2	3	5	6	1	3	15
										TOTAL	240

TABLE 5

Overview of top five and bottom five interventions for reducing irrigation or water applied, reducing evapotranspiration (ET), increasing crop yield or water productivity (WP-ET) per theme: water management (blue), soil or land management (yellow) and agronomy (green)

	Less water applied	Less ET	More Yield	More WP-ET
Top 5	Drip irrigation	Regulated deficit irrigation	Fertilizers	Fertilizers
	Regulated deficit irrigation	Timing of planting/ sowing	Sub-surface irrigation	Cultivars: short duration
	Alternate wetting and drying	Crop rotation	Timing of planting/ sowing	Cultivars: high yields
	Pipes	Cultivars: short duration	Drip irrigation	Mulching
	Sprinkler irrigation	Sub-surface irrigation	Pipes	Drip irrigation
	Range: -46% to -27%	**Range: -27% to -10%**	**Range: 84% to 20%**	**Range: 62% to 11%**
Bottom 5	Crop rotation	Drip irrigation	Regulated deficit irrigation	Regulated deficit irrigation
	Cultivars: high yields	Zero tillage	Crop rotation	Alternate wetting and drying
	Timing of planting/ sowing	Pipes	Cultivars: short duration	Surge irrigation
	Zero tillage	Cultivars: high yields	Border/furrow irrigation	Border/furrow irrigation
	Border/furrow irrigation	Alternate wetting and drying	Alternate wetting and drying	Crop rotation
	Range: -15% to 8%	**Range: 0% to 9%**	**Range: 1% to -23%**	**Range: 1% to -13%**

Note: The range between first and fifth intervention is indicated as the reported percent change due to the intervention as averaged in Table 6 (see Annex 2).

BOX 3

From reported water savings to practical implementation
What drives decision-makers to change?

Farmers are interested in increasing their reliable income. We know little about actual cost/benefit; however, as water becomes scarcer, these are interventions they can consider to increase production. The decision to adopt these interventions will depend on the amount of risk involved. Trade-offs balance the economic risks and potential profits.

Extension agents are responsible for communicating research information to farmers. They share the interest of the farmers in increasing farm incomes and should know which interventions are cost-effective under what conditions.

Neither of these two groups has any interest in ‘saving’ water except to increase beneficial consumption.

Scheme managers (of irrigation districts) may be interested in these interventions if there is shortage at tail ends (end of canal water users), or more commonly if groundwater is over-abstracted.

Planners and policymakers are the priority target group for the ‘real water savings’ issue as the effects are more immediate in their realm of managing water resources at a basin scale.

5. Interventions

This chapter provides guidelines on various crop water productivity interventions, including background, details on implementation, suitability and potential impact at the field scale, and basin-scale water issues. Since interventions must always be location-specific with regard to climate, socio-economic context, political preferences, governance mechanisms, etc., they should be considered as options for consideration rather than rigid guidelines.

The interventions are based on the framework defined in Chapter 3. Chapter 4 described the actual range of interventions. This chapter adds a mix of scientific literature, reports, websites and experiences to further characterize the interventions. Expert knowledge has been used to combine these sources and exact referencing has not been possible.

The interventions are grouped under the following themes: water management, soil and land management, and agronomy. An indication is provided for each intervention if the beneficial water consumption, non-beneficial water consumption, and return flow (concepts explained in Box 1) are expected to be higher or lower compared to a scenario without the intervention.

Border/furrow irrigation		
Theme: Water	Category: On-field irrigation	
Overview: These are traditional irrigation practices in which water is brought to the field from canals or pumped from groundwater.		
Climate zone: All	Crop type: All	Scale: Field, system
Consumption beneficial: Higher	Consumption non-beneficial: Higher	Return flow: Higher
Impact at field scale: • higher yields compared to no irrigation; • high level of drainage, runoff and percolation.		
Impact at basin scale: • Large return flows.		
Details: Border and furrow irrigation are among the most traditional irrigation methods and are applied widely. Border irrigation is generally best suited to larger fields with deep homogenous loam, or clay soils with medium infiltration rates. It is mainly applied to close-growing crops, such as pasture or alfalfa. Furrow irrigation consists of narrow, parallel channels with crops growing on the ridges between the furrows. Furrow irrigation is suitable for row crops that would be damaged if water covered their stem or crown. Implementing border and furrow irrigation requires a distribution system from canals and/or pumping from groundwater. Reported irrigation efficiencies are in the range of 40 percent to 70 percent. Focus should be on reuse by downstream users, thus minimizing non-recoverable return flows.		

Sprinkler irrigation		
Theme: Water	Category: On-field irrigation	
Overview: Irrigation uses sprinkler systems, pumping is needed to ensure sufficient pressure.		
Climate zone: All	Crop type: All, except paddy rice	Scale: Field, system
Consumption beneficial: Higher	Consumption non-beneficial: Higher	Return flow: Lower
Impact at field scale: • irrigation can use lower application rates; • non-beneficial consumption by evaporation from wind losses; • reduced drainage, runoff and percolation.		
Impact at basin scale: • smaller return flows (with a potential impact on third-party users); • lower irrigation demands; • highly reliable irrigation supply system needed.		
Details: Sprinkler irrigation applies irrigation water in a manner similar to natural rainfall. Water is pumped through a system of pipes. The pipe system, sprinklers and operating conditions must be designed to ensure a uniform application of water. Sprinker irrigation can be used for most crops and water can be sprayed over or under the crop canopy. Sprinklers can be used on almost all soil types, with the exception of soils that are sensitive to developing crusts. Sprinkler systems are often chosen for their higher irrigation efficiency. Return flows are generally lower than with basin, border and furrow irrigation systems. However, systems that are converted to sprinkler often experience a remarkable increase in water consumption, while the reduction in water intake (i.e water quotas) is often not established or accepted by farmers, resulting in an overall increase in water consumption at the basin scale.		

Drip irrigation		
Theme: Water	Category: On-field irrigation	
Overview: Irrigation is applied using emitters or drippers; pumping is needed to achieve sufficient pressure.		
Climate zone: All	Crop type: All, except paddy rice	Scale: Field, system
Consumption beneficial: Higher	Consumption non-beneficial: Lower	Return flow: Lower
Impact at field scale: • irrigation can use very low application rates and high frequency; • greatly reduced drainage, runoff and percolation; • salinity risks without leaching during the wet season.		

Impact at basin scale:

- very low return flows (with a potential impact on third-party users);
- lower irrigation demands;
- very highly reliable irrigation supply system needed.

Details:

Drip irrigation trickles water onto the soil at very low rates from a system of small diameter plastic pipes that are fitted with outlets called emitters or drippers. Water is applied close to the plants so that only the part of the soil in which the roots grow is wetted (unlike surface and sprinkler irrigation, which involves wetting the whole soil profile). With drip irrigation water, applications are more frequent than with other methods (usually every one to three days) and this provides a very high moisture level in the root zone of the soil.

Drip irrigation systems are often chosen for their greater efficiency. Return flows are generally very low. However, systems that are converted to drip irrigation often experience a remarkable increase in water consumption, while the reduction in water intake (i.e water quotas) is often not established or accepted by farmers, resulting in an overall increase in water consumption at the basin scale.

Subsurface irrigation

Theme: Water	Category: On-field irrigation	

Overview:

Subsurface drip irrigation involves the uniform application of small quantities of water at frequent intervals below the soil surface from discrete emission points or line sources.

Climate zone:	Crop type:	Scale:
All	All, except paddy rice	Field, system
Consumption beneficial:	Consumption non-beneficial:	Return flow:
Higher	Lower	Lower

Impact at field scale:

- irrigation can use low application rates and high frequency;
- very reduced drainage, runoff;
- salinity risks without leaching by rainy season.

Impact at basin scale:

- very low return flows (with a potential impact on third-party users);
- low irrigation demands;
- very high reliable irrigation supply system needed.

Details:

Subsurface irrigation is a low-pressure, high efficiency irrigation system that uses buried drip tubes or drip tape to meet crop water needs. Lateral depths range from 0.02 to 0.70 m and lateral spacings range from 0.25 to 5.0 m. Water is applied directly to the root zone of the crop and not to the soil surface so that non-beneficial consumption (evaporation from soil and irrigation water) will be minimized.

Subsurface irrigation systems are often chosen for their greater efficiency. Return flows are generally very low and are mainly restricted to groundwater recharge (especially during the start of the season when roots are not well developed). However, systems that are converted to subsurface irrigation often experience a remarkable increase in water consumption, while the reduction in water intake (i.e water quotas) is often not established or accepted by farmers, resulting in an overall increase in water consumption at the basin scale.

Supplemental irrigation		
Theme: Water	Category: On-field irrigation	
Overview: Irrigation is applied during drought-sensitive growth stages of the crop. Outside these periods, irrigation is limited.		
Climate zone: All	Crop type: All, except paddy rice	Scale: Field
Consumption beneficial: Lower	Consumption non-beneficial: Neutral	Return flow: Lower
Impact at field scale: • lower yields; • higher water productivity; • reduced drainage, runoff and percolation.		
Impact at basin scale: • reduction in return flows (with a potential impact on third-party users); • reduction in water withdrawal possible, assuming farmers accept a water allocation/quota system.		
Details: Supplemental irrigation is an optimization strategy that applies irrigation during drought-sensitive growth stages of a crop. Outside of these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water. Water restriction is limited to drought-tolerant phenological stages, often the vegetative stages and the late ripening period. Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle. While this inevitably results in plant drought stress and consequently in production loss, water productivity might increase. Supplemental irrigation is relatively easy to implement. Farmers often have knowledge about the sensitive stages of their crops. The reliability of the water supply is key to success. The expected level of impact depends on the 'intensity' of the supplemental irrigation (e.g. 90 percent, 80 percent, 70 percent of crop water requirements).		

Surge irrigation		
Theme: Water	Category: On-field irrigation	
Overview: Surge irrigation involves the intermittent application of water to improve distribution uniformity along a furrow.		
Climate zone: All	Crop type: All, except paddy rice	Scale: Field
Consumption beneficial: Neutral	Consumption non-beneficial: Neutral	Return flow: Lower
Impact at field scale: • Reduced runoff		
Impact at basin scale: • Reduction in return flows (with a potential impact on third-party users)		

Details:

Surge irrigation is the intermittent application of irrigation water (every 5-10 minutes) to improve distribution uniformity along a furrow. It works on the principle that dry soil infiltrates water faster than wet soil. Wet soil seals as the soil particles at the surface consolidate. When water is reintroduced in a furrow that has been wet, the wetting front moves quickly past the wetting zone to dry soil. At the wetting interface, dry soil slows the advance. This allows a faster advance through the field with less deep percolation and better application uniformity.

Surge irrigation uses a programme of cycle times (on-off) that account for the advance of the water front along the furrow (normally 5-10 minutes). The intermittent application reduces the tailwater volume because the water is moving as a pulse over the sealed furrow to the end of the furrow. Its velocity decreases as it moves along the furrow and has more time to infiltrate before it leaves the furrow. When set properly, very little tailwater leaves the furrow.

Surge flow irrigation can be successfully implemented on clay and cracking clay soils and clay loams – using borders as well as furrows. It should result in less deep percolation through better irrigation uniformity, as well as reduced runoff. It is complex to manage and requires instrumentation and automation in order to be attractive to farmers.

Alternate wetting and drying		
Theme: Water	Category: On-field irrigation	
Overview: Alternate wetting and drying (AWD) is practiced on paddy rice using controlled and intermittent irrigation.		
Climate zone: All	Crop type: Paddy rice	Scale: Field
Consumption beneficial: Neutral	Consumption non-beneficial: Neutral	Return flow: Lower
Impact at field scale: • substantial reduction in runoff; • partial reduction in bare-soil evaporation; • reduction in drainage and percolation.		
Impact at basin scale: • reduction in return flows (with a potential impact on third-party users).		
Details: AWD is a water management technique used to cultivate irrigated lowland rice. It differs from the usual system of maintaining continuous standing water in the crop field. AWD employs a method of controlled and intermittent irrigation. A periodic drying and re-flooding irrigation scheduling approach is followed in which the fields are allowed to dry for few days before re-irrigation, without stressing the plants. It is claimed that AWD reduces water demand for irrigation without reducing crop yields, although the impact on beneficial consumption is not well described. Moreover, reliable water supply is essential since no buffer in the field is available. In addition, increased weed development has been reported as a significant negative effect.		

Canal lining		
Theme: Water	Category: Irrigation infrastructure	
Overview: Canal lining is the process of reducing seepage flow of irrigation water by adding an impermeable layer to the edges of the trench.		
Climate zone: All	Crop type: All	Scale: System
Consumption beneficial: Neutral	Consumption non-beneficial: Lower	Return flow: Neutral
Impact at field scale: N/A		
Impact at basin scale: • reduction in return flows (with a potential impact on third-party users).		
Details: Seepage flows can be 30 to 50 percent of the irrigation water from canals. By making a canal less permeable, the water velocity increases, resulting in a greater overall discharge. Increased velocity also reduces the amount of evaporation and silting that occurs. Canal lining is also used to prevent weed growth, which can spread throughout an irrigation system and reduce water flow. Lining a canal can also prevent waterlogging around low-lying areas of the canal. Since seepage flows are often reused, actual water savings from lining at the system scale can be relatively small. Since canal linings are exposed to the elements and are in constant use, they are susceptible to damage over time. Moreover, canal lining can be very costly.		

Piped irrigation system		
Theme: Water	Category: Irrigation infrastructure	
Overview: A piped irrigation system is a network installation consisting of pipes, fittings and other devices to supply water under pressure from the source of the water to the irrigable area.		
Climate zone: All	Crop type: All	Scale: System
Consumption beneficial: Neutral	Consumption non-beneficial: Lower	Return flow: Neutral
Impact at field scale: N/A		
Impact at basin scale: • reduction in return flows (with a potential impact on third-party users).		

Details:

The pipelines that convey and distribute irrigation water to the individual plots are usually buried and are thus protected from farming operations and traffic hazards. Surface offtake hydrants can be located at various spots according. With surface methods, the irrigation water can be delivered directly to open ditches feeding the furrows or the basins.

Pipes are a prerequisite for sprinkler and drop irrigation, both of which require pressure.

In a piped irrigation system, flows can be very small, even 1 m3 per hour can be utilized. The route direction of the flow is not bound by gravity; a piped system conveys and distributes the irrigation water following the most convenient (shortest) route, regardless of the slope and topography of the area. Piped irrigation systems require a certain pressure, from two to three bars, which is provided by a pumping unit or a supply tank situated at a high point.

Greenhouse		
Theme: Water	Category: Moisture recycling	
Overview: Greenhouses (or protected agriculture) are very expensive but have the potential to save water and protect the environment.		
Climate zone: Dry	Crop type: Vegetables	Scale: Field
Consumption beneficial: Lower	Consumption non-beneficial: Lower	Return flow: Neutral
Impact at field scale: • lower water demand due to moisture recycling.		
Impact at basin scale: • reduction in return flows (with a potential impact on third-party users); • lower application demands.		
Details: Protected agriculture using greenhouses is an agricultural production system mainly suited for dryer conditions and high-value crops (e.g. vegetables, flowers). The system requires minimal amounts of water due to moisture recycling. Greenhouses can yield up to five times the land productivity and seven times the water productivity of open cultivated lands. They provide safety and significant protection against pests and diseases for high-value crops. Greenhouse cultivation is also particularly suited to offset the effects of climate change, since it is based on controlled climate parameters, including temperature, humidity, light and day length, wind and carbon dioxide concentration. Greenhouses require huge investments and sophisticated knowledge is essential.		

Hydroponics		
Theme: Water	Category: Moisture recycling	
Overview: Hydroponics and hydroculture does not require soil and is mainly practiced in greenhouses.		
Climate zone: All	Crop type: High-value crops	Scale: Field
Consumption beneficial: Lower	Consumption non-beneficial: Lower	Return flow: Neutral
Impact at field scale: • lower water demand by moisture recycling.		
Impact at basin scale: • reduction in return flows (with a potential impact on third-party users), • lower application demands.		
Details: Hydroponics involves growing plants in a liquid growing medium solution. Hydroculture uses an inorganic solid (or inert) growing medium.The inert growing medium is usually rock-based, typically expanded clay aggregates. Hydroponics and hydroculture generally require less water as return flows are very low. Nutrients and chemicals can be supplied in very precise amounts.		

Zero tillage		
Theme: Soil and land	Category: Tillage	
Overview: Zero tillage is an agricultural technique for growing crops or pasture without disturbing the soil through tillage.		
Climate zone: All	Crop type: All	Scale: Field
Consumption beneficial: Neutral	Consumption non-beneficial: Higher	Return flow: Lower
Impact at field scale: • high level of non-beneficial consumption by weeds.		
Impact at basin scale: • lower water availability.		
Details: Zero tillage farming decreases the amount of soil erosion that tillage causes in certain soils, especially in sandy and dry soils on sloping terrain. Other possible benefits include an increase in the amount of water that infiltrates the soil, soil retention of organic matter and nutrient cycling. This may increase the amount and variety of life in and on the soil. Typically, no-tillage systems require the use of very large amounts of herbicides to control weeds. Tillage is dominant in agriculture today, but no-till methods may have success in some contexts. In some cases, low-till methods can combine till and no-till methods. For example, some approaches may use a limited amount of shallow disc harrowing but no ploughing. Water consumption from no-till farming is generally high, driven by the large amount of weeds.		

Tillage		
Theme: Soil and land	Category: Tillage	
Overview: Tillage involves the preparation of soil for agriculture by mechanical agitation of various types, such as digging, stirring, and overturning.		
Climate zone: All	Crop type: All	Scale: Field
Consumption beneficial: Neutral	Consumption non-beneficial: Lower	Return flow: Neutral
Impact at field scale: • reduction in non-beneficial consumption by weeds; • enhanced infiltration.		
Impact at basin scale: • dependent on soil type		
Details: Tillage is not an intervention as such, but a standard practice in modern agriculture. In terms of water resources and irrigation, the impact varies widely depending on the type of tillage, soil type and timing. Primary tillage is usually conducted after the last harvest, when the soil is wet enough to allow plowing but also allows good traction. Some soil types can be plowed dry. The objective of primary tillage is to attain a reasonable depth of soft soil, to incorporate crop residues, kill weeds and aerate the soil. Secondary tillage is any subsequent tillage, used to incorporate fertilizers, reduce the soil to a finer tilth, level the surface and control weeds. In general, tillage destroys weeds (and breaks the capillary rise, generating a mulching effect and reducing non-beneficial consumption), dries the soil, impacts infiltration capacity, loosens soil and increases water storage capacity, among other impacts. However, soil type is a major factor in determining how those processes will take place.		

Field levelling		
Theme: Soil and land	Category: Land grading	
Overview: Field levelling is a process for ensuring that the depth and discharge variations over the field are relatively uniform and, as a result, that water distribution in the root zone is also uniform.		
Climate zone: All	Crop type: All	Scale: Field
Consumption beneficial: Neutral	Consumption non-beneficial: Neutral	Return flow: Lower
Impact at field scale: • reduction in runoff; • potential increase in drainage and percolation.		

Impact at basin scale: • reduction in drainage; • increased groundwater percolation.	
Details: Field levelling has two distinct forms. During the construction or rehabilitation of irrigation systems, fields will be levelled, normally involving large amount of soil transportation. Small-scale levelling is performed by farmers every year to recuperate the land from farming and tillage. Levelling, smoothing and shaping the field surface are as important to the surface system as the design of laterals, manifolds, risers and outlets is for sprinkler or trickle irrigation systems. A field levelled to high standards is generally more easily irrigated than one where undulations require special attention. In theory, land levelling should allow more even and rapid surface irrigation (border, basin, flood). If flow rates and times are managed properly, the irrigation uniformity should be higher and deep percolation and drainage should be reduced compared to unlevelled fields.	

Terracing		
Theme: Soil and land	Category: Land grading	
Overview: A terrace is a piece of sloped plane that has been cut into a series of successively receding flat surfaces or platforms resembling steps for the purposes of more effective farming.		
Climate zone: Wet	Crop type: All	Scale: Field, system
Consumption beneficial: Higher	Consumption non-beneficial: Neutral	Return flow: Lower
Impact at field scale: • reduction in runoff; • potential increase in drainage and percolation.		
Impact at basin scale: • reduction in runoff.		
Details: Graduated terraces are commonly used to farm on hilly or mountainous terrain. Terraced fields decrease both erosion and surface runoff and may be for growing crops that require irrigation, such as rice. Infiltration rates are often very high in terraces, but this is misleading since interflow between terraces, as well as terrace-to-terrace flow, mean that you must look at the average water use over a much larger area to estimate actual water delivery.		

Block-end or soil bunds		
Theme: Soil and land	Category: Land grading	
Overview: Block-end or soil bunds are placed at the end of a field to avoid runoff of irrigation water.		
Climate zone: All	Crop type: All	Scale: Field

Consumption beneficial:	Consumption non-beneficial:	Return flow:
Neutral	Neutral	Lower

Impact at field scale:

- reduction in runoff;
- potential increase in drainage and percolation.

Impact at basin scale:

- reduction in runoff.

Details:

Block-end or soil bunds (risers) are often combined with terracing. Terraces are a series of level or virtually level strips running across the slope at vertical intervals, supported by steep banks or risers.

There are two main types of risers associated with the two types of terraces. Irrigation or level bench terraces are used for crops, such as rice, that need flood irrigation and impounding water. Upland bench terraces are mostly used for rain-fed crops or crops that only require irrigation during the dry season. They are generally sloped for drainage.

Fertilizers

Theme: Agronomy — Category: Supplements

Overview:

Fertilizers are inorganic materials that supply nutrients and trace elements to the soil to encourage the growth of crops.

Climate zone:	Crop Type:	Scale:
All	All	Field
Consumption beneficial:	Consumption non-beneficial:	Return flow:
varies	Lower	varies

Impact at field scale:

- enhanced crop growth and higher water productivity.

Impact at basin scale:

- higher water productivity.

Details:

Nutrients help to maximize the amount of water used productively. Water is consumed in crop fields either through productive transpiration or non-productive soil evaporation.

The evaporation of water from the soil is reduced when the surface is shaded under a crop canopy, leaving more water available for plant transpiration. Well-fertilized and healthy crops have more vigorous and extensive root systems that go deeper into the soil to access more stored water. The extra water allows transpiration to continue longer so more photosynthesis can occur. Adequate plant nutrition also enables crops to establish roots more quickly to access water before it percolates from the soil profile.

Through the two mechanisms – increased transpiration and accessing more water – water productivity increases with the use of fertilizer. Good early nutrition improves crop competiveness. A crop that is well supplied with nutrients will rapidly cover the soil surface, which not only reduces soil evaporation but also increases crop competitiveness against weeds.

Growth enhancers		
Theme: Agronomy	Category: Supplements	
Overview: Crop enhancers (plant growth regulators or PGRs) have varied effects on the growth and development of crops, depending on the type of PGR.		
Climate zone: All	Crop type: All	Scale: Field
Consumption beneficial: Varies	Consumption non-beneficial: Varies	Return flow: varies
Impact at field scale: • very diverse.		
Impact at basin scale: • very diverse.		
Details: PGR describes many agricultural and horticultural chemicals that influence plant growth and development. In fact, PGRs are hormones that affect gene expression and transcription levels, cellular division and growth. PGRs are chemical components that can be produced and applied to crops. Very small doses are required. PGRs are not yet widespread, but according to various studies they could become very important in influencing plant processes, such as drought resistance, higher yields, faster leaf development among many others. PGRs also have the potential to substantially increase water productivity. There are a quite diverse range of PGRs and the topic needs additional research.		

Crop rotation		
Theme: Agronomy	Category: Crop selection	
Overview: Crop rotation is the pratice of growing different crops at different times on the same piece of land; cropping patterns relate to the timing and arrangement of crops on a particular land area.		
Climate zone: All	Crop Type: All	Scale: Field
Consumption beneficial: Varies	Consumption non-beneficial: Varies	Return flow: Varies
Impact at field scale: • very diverse.		
Impact at basin scale: • very diverse.		
Details: The choice of crops and the use of cropping patterns/rotations are probably the most important factors in water consumption, water productivity and economic return. Farmers often replace crops that consume a great deal of water (e.g. rice, sugarcane) with crops that consume less water. Obviously, water is not the only the driving force for crop replacement, but economic returns in most cases drive decisions around what to grow as do farmer knowledge and cultural food preferences.		

High-yielding cultivars		
Theme: Agronomy	Category: Crop selection	
Overview: This intervention involves the use of crop cultivars with high-yielding characteristics.		
Climate zone: All	Crop type: All	Scale: Field
Consumption beneficial: Higher	Consumption non-beneficial: Neutral	Return flow: Lower
Impact at field scale: • enhanced crop growth and higher water productivity; • greater transpiration can be expected.		
Impact at basin scale: • higher water demand; • higher water productivity.		
Details: High-yielding crop varieties developed by classical plant breeders have been essential for generating adequate food supplies, such as during the Green Revolution in the 1960s when the development of modern varieties increased agricultural production worldwide. Advances in genetics and genomics have accelerated progress in plant breeding. Past techniques have been limited mainly to selection among phenotypes (visible traits in the field), but are now combined with genetic research to support an integrated breeding approach. Genetic modification can produce high-yielding cultivars, although their acceptance by the public is not universal. Dependency on seed suppliers is another point of contention. The overall impact of high-yielding varieties on water can vary. In some cases more water will be consumed by crop transpiration, in parallel with increases in water productivity.		

Short-duration cultivars		
Theme: Agronomy	Category: Crop selection	
Overview: This intervention involves the use of crop cultivars with a short growing season.		
Climate zone: All	Crop type: All	Scale: Field
Consumption beneficial: Lower	Consumption non-beneficial: Neutral	Return flow: Higher
Impact at field scale: • lower crop water demand.		
Impact at basin scale: • lower irrigation demand.		
Details: Crop breeding has created crop varieties with shorter growing seasons. These improved cultivars are available for many crops, including rice, wheat and maize. Most have been selected for their 'dwarf' characteristics, where the fraction of stem and leaves relative to the storage organs has been improved. The overall impact of short duration cultivars is lower crop transpiration without much impact on yield, saving water and improving water productivity.		

Rooting depth of cultivars

Theme: Agronomy	Category: Crop selection	

Overview:

This intervention uses crop cultivars with deeper rooting systems.

Climate zone:	Crop type:	Scale:
All	All	Field

Consumption beneficial:	Consumption non-beneficial:	Return flow:
Higher	Neutral	Lower

Impact at field scale:

- lower irrigation demand.

Impact at basin scale:

- reduced return flows (with potential impact on third-party users);
- lower water demand.

Details:

Breeders have developed cultivars with deeper and better developed rooting systems. These are sometimes marketed as drought resistant because they can draw water from deeper soil layers. If precipitation outside the growing season replenishes the soil water storage sufficiently, cultivars with enhanced rooting systems might be effective. In other cases, it might lead to lower percolation and or drainage, thus requiring proper impact analysis at the basin level.

Timing of planting/sowing

Theme: Agronomy	Category: Crop selection	

Overview:

This intervention optimizes planting or sowing dates to make better use of water resources.

Climate zone:	Crop type:	Scale:
All	All	Field

Consumption beneficial:	Consumption non-beneficial:	Return flow:
Varies	Varies	Varies

Impact at field scale:

- very diverse.

Impact at basin scale:

- very diverse.

Details:

It is evident that planting or seeding should be done at the right moment to benefit from the best climate conditions (rainfall, temperature, sunshine). However, this is not always possible for various reasons. For example, the prices for harvested products are often higher outside the traditional harvesting season. Farmers' habits, labour shortages, and/or a lack of seasonal forecasting may impede optimized timing.

The impact of optimized timing of planting/sowing on water consumption depends on the actual implementation of this intervention. If implemented optimally, higher yields can be achieved with a slight increase in water consumption, resulting in an overall higher water productivity.

Planting density		
Theme: Agronomy	Category: Crop selection	
Overview: This intervention relates to the amount of space left between plants in the field. The more closely spaced the plants, the higher the planting density.		
Climate zone: All	Crop type: All	Scale: Field
Consumption beneficial: Higher	Consumption non-beneficial: Lower	Return flow: Neutral
Impact at field scale: • very diverse.		
Impact at basin scale: • very diverse.		
Details: Optimal planting density depends on many factors, including soil fertility, labour, machinery, water availability and climate. In some cases, lower planting density can be effective in capturing more rain per plant and/or reducing irrigation demand. On the other hand, higher planting density can be very effective in reducing soil evaporation and non-beneficial water consumption by weeds.		

Mulching		
Theme: Agronomy	Category: Coverage	
Overview: This intervention involves covering the soil with mulch material, either crop residues or material brought to the field (e.g. plastic, bark chips).		
Climate zone: All	Crop type: All	Scale: Field
Consumption beneficial: Neutral	Consumption non-beneficial: Lower	Return flow: Higher
Impact at field scale: • reduced non-beneficial evaporation.		
Impact at basin scale: • lower water demand; • reduced erosion.		
Details: Mulch is a layer of material applied to the surface of the soil. Mulch can conserve soil moisture, improve the fertility and health of the soil, and/or reduce weed growth. Mulch can be organic or artificial. Organic mulch can be created by tilling the remains of the previous crop. Organic material such as bark chips and straw can also be used. Plastic sheeting is commonly used, especially in China. Many experiments with mulching have reported substantial water savings and options for expanding the growing season (earlier planting) due to temperature regulation. From a water savings perspective, mulching can be very effective. Labour availability and cost are important considerations when applying this intervention.		

Shading		
Theme: Agronomy	Category: Coverage	
Overview: Shading interventions aim to reduce the amount of sunlight focused on crops and/or soil.		
Climate zone: Hot	Crop type: All	Scale: Field
Consumption beneficial: Neutral	Consumption non-beneficial: Lower	Return flow: Neutral
Impact at field scale: • reduction in non-beneficial consumption.		
Impact at basin scale: • reduced water demand.		
Details: Crops can be shaded by covering the fields with nets or by planting taller crops/trees close to the primary crop. Shading protects plants from high temperatures and therefore excessive evaporation. It also reduces soil evaporation. The water consumption of an entire field might increase when shading uses taller crops, and especially trees. Thus a proper cost/benefit analysis of this type of shading is essential. Shading by nets might be expensive and labour-intensive.		

Weed control		
Theme: Agronomy	Category: Coverage	
Overview: Weed control uses chemical, mechanical, crop management and biological technologies.		
Climate zone: All	Crop type: All	Scale: Field
Consumption beneficial: Neutral	Consumption non-beneficial: Lower	Return flow: Higher
Impact at field scale: • reduced non-beneficial transpiration; • more space for crops.		
Impact at basin scale: • reduction in non-beneficial consumption.		
Details: There are many methods of weed control. Successful weed control often requires the combination or sequential use of several methods (known as integrated weed management). The main methods include manual, mechanical, crop management, grazing, biocontrol, herbicides, prescribed fire, solarization, flooding, and a range of novel techniques. The overall objective of weed control is to reduce competition with crop requirements for water, space, nutrients and sun. The actual 'savings' in terms of water might be small, since the crop that replaces the weed also consumes water. However, water productivity enhancement can be achieved by the shift from non-beneficial consumption to beneficial consumption.		

Cover crops		
Theme: Agronomy	Category: Coverage	
Overview: A cover crop is grown primarily to benefit the soil rather than to improve crop yield.		
Climate zone: All	Crop type: All	Scale: Field
Consumption beneficial: Higher	Consumption non-beneficial: Neutral	Return flow: Lower
Impact at field scale: • additional water consumption by cover crop		
Impact at basin scale: • additional water consumption by cover crop		
Details: Cover crops are typically grasses or legumes but may include other green plants. They are commonly used to suppress weeds, manage soil erosion, help build and improve soil fertility and quality, control diseases and pests and promote biodiversity. Most often, a cover crop is grown in the off-season. In essence, a cover crop readies the land for an upcoming cash crop. Cover crops reduce the amount of water that drains off a field and can enhance groundwater percolation. At the same time, cover crops consume water by transpiration and might reduce soil moisture availability for the main crop. As with many other interventions, soil and climate conditions determine the impact of this intervention.		

Pesticides		
Theme: Agronomy	Category: Disease control	
Overview: This intervention protects crops through the use of pesticides.		
Climate zone: All	Crop type: All	Scale: Field
Consumption beneficial: Higher	Consumption non-beneficial: Neutral	Return flow: Lower
Impact at field scale: • enhanced crop growth and higher water productivity.		
Impact at basin scale: • higher water productivity.		
Details: Using pesticides to protect plants from pests and diseases is a widespread practice. The impact of pesticide use on water productivity is that pesticides reduce yield losses, thereby achieving higher productivity.		

Biological disease and pest control		
Theme: Agronomy	Category: Disease control	
Overview: This intervention protects crops using biological (organic) measures.		
Climate zone: All	Crop type: All	Scale: Field
Consumption beneficial: Higher	Consumption non-beneficial: Neutral	Return flow: Lower
Impact at field scale: • enhanced crop growth and higher water productivity.		
Impact at basin scale: • higher water productivity.		
Details: Biological plant protection controls pests and diseases by introducing natural enemies of the harmful organisms and biological plant protection products. A wide range of biological crop protection options exists, including biological pesticides (biopesticides), pheromones, and signal rollers. Like fertilizers, using pesticides reduces losses thus enabling higher yields.		

Leaching		
Theme: Agronomy	Category: Salinity management	
Overview: This intervention uses water to leach salts out of the root zone.		
Climate zone: Dry	Crop type: All	Scale: Field, system
Consumption beneficial: Higher	Consumption non-beneficial: Higher	Return flow: Lower
Impact at field scale: • increased water demand; • higher crop yields.		
Impact at basin scale: • very high water demand; • water logging risk.		
Details: Leaching saline lands involves the removal of excess salts from arable and subsurface soil horizons by flushing them with water. Primary salinization develops through plant and soil evapotranspiration where only water is removed and the salt remains. Secondary salinization happens if saline groundwater reaches the root zone. Leaching can happen naturally if rainfall is high during a season. In other cases, farmers have to apply more irrigation than the crop actually requires. It is important that a extensive drainage system is available to drain the saline water into the sea or evaporation ponds. Obviously, leaching requires a large quantity of water that cannot be reused.		

Salt-tolerant crop types		
Theme: Agronomy	Category: Salinity management	
Overview: This intervention uses crop cultivars that can withstand higher salinity levels.		
Climate zone: Dry	Crop type: All	Scale: Field
Consumption beneficial: Higher	Consumption non-beneficial: Higher	Return flow: Lower
Impact at field scale: • higher crop yields.		
Impact at basin scale: • more land suitable for agriculture.		
Details: Over the past two decades, traditional breeding programmes have achieved considerable improvements in the salt tolerance of important crop species such as barley, rice, pearl millet, maize, sorghum, alfalfa and many grass species. Genetic studies and modifications might boost the development of salt-tolerant crops. The overall impact of salt-tolerant varieties is very relevant for water productivity and water savings. Less water is needed for leaching and crops will produce higher yields under the same saline conditions.		

Conclusions

Achieving real water savings is complex and context-specific. This study provides information on the field-scale changes that might result from various interventions. The impact in a larger context will require analysis at district level or basin scale. The 'follow the water' concept introduces water accounting terms to communicate the categories of water flows in a system. Using the concepts and guidelines provided in this document, decision-makers can improve the management of water systems with sustainable interventions that accomplish real water savings.

The inventory provided in this report lists interventions that can lead to increases in water productivity and reductions in water consumption. Several interventions, mainly related to water management and irrigation, are commonly promoted as water savings technologies but the 'follow the water' approach indicates that reductions in water consumption are limited. Saving water is solely achieved by reducing water consumption and non-recoverable return flows.

Tools will be needed to translate the approach into practice and assist decision-makers to adopt the approach proposed in this guidance note. This guidance offers relevant information to assist decision-makers and translate field-scale interventions to a basin scale context. It requires a wider audience to continue this work and promote sustainable implementation of water productivity interventions.

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Annex 1. Inventory reference list

Title	Author(s)	Year	Reference type	Journal (if applicable)	Additional references cited by main publication
Effect and side-effect assessment of different agricultural water saving measures in an integrated framework	Raeisi *et al.*	2019	Scientific journal paper	Agricultural Water Management	Kiziloglu *et al.*, 2006.
Effects of deficit irrigation strategies on soil salinization and sodification in a semiarid drip-irrigated peach orchard	Aragues *et al.*	2014	Scientific journal paper	Agricultural Water Management	
Effects of seasonal water use and applied n fertilizer on wheat water productivity indices	Montazar *et al.*	2012	Scientific journal paper	Irrigation and Drainage	
Effect of different quantities of supplemental irrigation and its salinity on yield and water use of winter wheat (triticum aestivum)	Kiani *et al.*	2012	Scientific journal paper	Irrigation and Drainage	
Developing scenarios to assess sunflower and soybean yield under different sowing dates and water regimes in the Bekaa Valley (Lebanon): simulations with Aquacrop	Saab *et al.*	2014	Scientific journal paper	International Journal of Plant Production	
Assessing potential water savings in agriculture on the Hai Basin Plain, China	Yan *et al.*	2015	Scientific journal paper	Agricultural Water Management	Zhou *et al.*,1996; Zhao *et al.* 1996; Hu, 1992; Wang & Xu, 1991; Wang *et al.*, 201; Fan & Wang, 2010; Zhu & Wang, 1996; Chen, 2005; Sun *et al.*, 2010; Fang *et al.*, 2010; Zhang *et al.*, 2004; Liu *et al.*, 2008; Liu, 2007; Chen *et al.*, 2004; Shen *et al.*, 2002; Zhang *et al.*, 2010.

Water resources and water use efficiency in the North China Plain: current stats and agronomic management options	Fang *et al*.	2010	Scientific journal paper	Agricultural Water Management	Su *et al*., 1999; Zhang et al., 2000; Zhang et al., 2002; Zhang et al., 2006; Chen *et al*., 2006; Li *et al*., 2007; Zhao *et al*., 1996; Zhu *et al*,. 2000; Chen *et al*., 2002; Zhang *et al*., 2003; Zhang *et al*., 2004; Chen *et al*., 2007; Wang *et al*., 2007; Zhao *et al*., 1999; Zhong *et al*., 2000; Li *et al*., 2000; Wu & Yang, 2004; Dang *et al*., 2006; Yi *et al*., 2008; Shan *et al*., 2006.
Effects of winter wheat row spacing on evapotranspiration, grain yield, and water use efficiency	Chen *et al*.	2010	Scientific journal paper	Agricultural Water Management	
Towards groundwater neutral cropping systems in the Alluvial Fans of the North China Plain	van Oort *et al*.	2016	Scientific journal paper	Agricultural Water Management	
Impact of irrigation method on water use efficiency and productivity of fodder crops in Nepal	Jha *et al*.	2016	Scientific journal paper	Climate	
Strategies to improve cereal production in the Terai region (Nepal) during dry season: simulations with AquaCrop	Shrestha *et al*.	2013	Scientific journal paper	Procedia Environmental Sciences	
Increasing yield stability and input efficiencies with cost-effective mechanization in Nepal	Park *et al*.	2018	Scientific journal paper	Field Crops Research	
Simulation of resource-conserving technologies on productivity, income, and greenhouse gas GHG emission in rice-wheat system	Sharawat *et al*.	2012	Scientific journal paper	Journal of Soil Science and Environmental Management	
Halting the groundwater decline in northwest India - which crop technologies will be winners?	Humpreys *et al*.	2010	Book chapter	Advances in Agronomy	Kahlown *et al*., 2006; Jat *et al*., 2006; Jat *et al*., 2009; Khepar *et al*., 1999; Arora, 2006; Choudhary, 1997; Hira *et al*., 2002; Humphreys *et al*., 2008a; Sandhu *et al*., 1980; Sharma, 1989,1999, Bushan *et al*., 2007; Kukal *et al*., 2010; Erenstein & Lakshmi, 2008.

Options for increasing productivity of the rice-wheat system of north west India while reducing groundwater depletion: Part I	Baldwinder-Singh *et al.*	2014	Scientific journal paper	Field Crops Research	
Options for increasing productivity of the rice-wheat system of north west India while reducing groundwater depletion: Part II	Baldwinder-Singh *et al.*	2015	Scientific journal paper	Field Crops Research	
Constraints and opportunities for water savings and increasing productivity through resource conservation technologies in Pakistan	Ahmad *et al.*	2013	Scientific journal paper	Agriculture, Ecosystems and Environment	Farooq *et al.*, 2007; Humphreys *et al.*, 2005,2010; Jehangir *et al.*, 2007.
Literature review on rebound effect on water saving measures and analysis of a Spanish case study	Berbel *et al.*	2014	Scientific journal paper	Water Resources Management	
Effects of modernization and medium term perspectives on water and energy use in irrigation districts	Fernández García et al.	2014	Scientific journal paper	Agricultural Systems	
Modernizing water distribution networks	Rodríguez Díaz *et al.*	2012	Article	Outlook on Agriculture	
Water and energy consumption after the modernization of irrigation in Spain	González-Cebollada	2015	Scientific journal paper	Sustainable Development	Lecina *et al.*, 2009; Stambouli, 2012; Ruiz *et al.*, 2008; Hydrographic Tajo Confederation, 2013; Fernández *et al.*, 2012.
Drip irrigation impacts on evapotranspiration rates in California's San Joaquin Valley	Thoreson *et al.*	2013	Scientific journal paper	International Commission on Irrigation and Drainage (ICID) conference paper	Burt *et al.*, 2002; Ward & Pulido-Velazquez, 2008.
Furrow irrigation management with limited water	Schneekloth *et al.*	2006	Scientific journal paper	The American Society of Agricultural and Biological Engineers (ASABE) conference paper	

Water saving technologies: myths and realities revealed in Pakistan rice-wheat systems	Ahmad *et al.*	2007	Technical report	International Water Management Institute (IWMI) Research Reports	
Impact assessment of rehabilitation intervention in Gal Oya Left bank	Amarasinghe *et al.*	1998	Technical report	IWMI Research Reports	
Subsurface drip irrigation in California – here to stay?	Ayars *et al.*	2015	Scientific journal paper	Agricultural Water Management	
Technical concepts related to conservation of irrigation and rainwater in agricultural systems	Clemmens *et al.*	2008	Scientific journal paper	Water Resources Research	
Use of crop simulation models to evaluate limited irrigation management options for corn in a semiarid environment	Saseendran *et al.*	2008	Scientific journal paper	Water Resources Research	Klocke *et al.*, 2004.
Economics of agricultural water conservation: empirical analysis and policy implications	Dagnino & Ward	2012	Scientific journal paper	International Journal of Water Resources Development	
Water productivity in the Zhanghe irrigation system: issues of scale	Dong *et al.*	2001	Book chapter	Water Saving for Rice	
On-farm impacts of zero tillage wheat in South Asia's rice-wheat systems	Erenstein *et al.*	2008	Scientific journal paper	Field Crops Research	
Microeconomics of deficit irrigation and subjective water response function for intensive olive groves	Expósito & Berbel	2016	Scientific journal paper	Water	
Adoption and impacts of zero-tillage in the rice-wheat zone of irrigated Punjab, Pakistan	Farooq *et al.*	2007	Technical report	International Maize and Wheat Improvement Center (CIMMYT)	Alsam *et al.*, 1989.
Adoption of drip irrigation in cotton: the case of kibbutz cotton growers in Israel	Feinerman & Yaron	1990	Article	Oxford Agrarian Studies	
Hydro-economic modelling of water scarcity under global change: an application to the Gállego river basin (Spain)	Graveline *et al.*	2014	Scientific journal paper	Regional Environmental Change	

Strategies for reducing subsurface drainage in irrigated agriculture through improved irrigation	Hanson & Ayars	2002	Scientific journal paper	Irrigation and Drainage Systems	Goldhamer & Peterson, 1984; Fulton *et al*., 1991; Boyle Engineering Corp, 1994.
Rice-wheat cropping systems in the Indo-Gangetic Plains: issues of water productivity in relation to new resource-conserving technologies	Hobbs & Gupta	2003	Book chapter	IWMI	Aslam *et al*., 1993; Gill *et al*., 2000.
Water saving in rice-wheat systems	Humpreys *et al*.	2005	Scientific journal paper	Plant Production Science	Kahlown *et al*., 2002; Rickman, 2002.
A comparative analysis of water application and energy consumption at the irrigated field level	Jackson *et al*.	2010	Scientific journal paper	Agricultural Water Management	
Enhancing water productivity at the irrigation system level: a geospatial hydrology application in the Yellow River Basin	Khan et al.	2008	Scientific journal paper	Journal of Arid Environments	
Water and energy conservation using irrigation scheduling with center-pivot irrigation systems	Kranz *et al*.	1992	Scientific journal paper	Agricultural Water Management	
Dripping water to a water guzzler: techno economic evaluation of drip irrigation of alfalfa in North Gujarat, India	Kumar *et al*.	2004	Scientific journal paper	Proceedings of the 2nd International Conference of the Asia Pacific Association of Hydrology and Water Resources	Lamm & Trooien, 1999; Ayars, 1999.
Water saving and yield enhancing micro-irrigation technologies in India: when and where can they become best bet technologies	Kumar *et al*.	2008	Article		Narayanamoorthy, 2004; Jadhav *et al*., 1990; Hapase *et al*., 1992; Narayanamoorthy, 1996; Reddy & Thimmegowda, 1997; Shiyani *et al*., 1999; Palanisamy *et al*., 2002.
Irrigation modernization and water conservation in Spain: the case of riegos del alto Aragón	Lecina *et al*.	2010	Scientific journal paper	Water Resources Management	
More crop per drop: how to make it acceptable for farmers?	Luquet *et al*.	2005	Scientific journal paper	Water Resources Management	
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Effects of conservation agriculture on Land and Water Productivity in Yellow River Basin, China	Nangia *et al.*	2010	Scientific journal paper	International Journal of Agricultural and Biological Engineering	
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Water savings through improved irrigation techniques: basin-scale quantification in semi-arid environments	Törnqvist & Jarsjö	2012	Scientific journal paper	Water Resources Management	
More rice, less water – integrated approaches for increasing water productivity in irrigated rice-based systems in Asia	Tuong *et al.*	2005	Scientific journal paper	Plant Production Science	Peng *et al.*, 1998; Tabbal *et al.*, 2002; Tuong, 2003.
Hydrologic impacts due to changes in conveyance and conversion from flood to sprinkler irrigation practices	Ven *et al.*	2004	Scientific journal paper	Journal of Irrigation and Drainage Engineering	

Annex 2.
Summary results inventory

The following table presents the average change in irrigation, evapotranspiration, crop yield, water productivity and irrigation water productivity resulting from each intervention. The number of studies used to compute the average is indicated in the 'count' column. Interventions cited by two or fewer publications are excluded from the table. A total of 240 studies were used for this study: 131 in the category of water management; 40 in the category of soil and land management, 54 in the category of agronomy and 15 other interventions that were not included in the intervention framework (irrigation scheduling, raised beds, etc.).

For the first two aspects, irrigation and evapotranspiration, reductions are indicated as negative values and are coloured green. These are perceived as desirable; however, a water accounting context (as described in Chapter 2) is required to determine whether real water savings are achieved. Increases in crop yield, water productivity (per unit of ET) and irrigation productivity (per unit of irrigation) are also in green.

TABLE 6

Inventory summary with average reported changes (%) in irrigation (I), evapotranspiration (ET), crop yield (Y), water productivity (WP), and irrigation water productivity (I-WP) for various field interventions

Interventions	Count	Change in I	Change in ET	Change in Y	Change in WP	Change in I-WP
Agronomy	54	-4%	-6%	19%	27%	12%
Coverage	24					
Mulching	24	0%	-3%	14%	14%	0%
Crop selection	18					
Crop rotation	4	8%	-19%	-14%	1%	15%
Cultivars: high yields	3		0%	10%	15%	
Cultivars: short duration	3	-23%	-18%	-2%	29%	22%
Timing of planting/sowing	6	-4%	-20%	36%	7%	-2%
Supplements	12					
Fertilizers	12			84%	62%	24%
Other (please specify)	15	-21%	2%	-4%	-16%	34%
Water management	131	-38%	-5%	14%	41%	50%
On-field irrigation	124					
Alternate wetting and drying	3	-37%	0%	1%	-7%	31%
Border/furrow irrigation	3	-15%		0%		5%
Deficit irrigation	27	-38%	-27%	-23%	-13%	57%
Drip irrigation	67	-46%	9%	29%	11%	87%

Sprinkler irrigation	12	-27%		14%		-2%
Sub-surface irrigation	6	-15%	-10%	62%		33%
Surge irrigation	6	-22%	0%	0%	-3%	6%
Irrigation infrastructure	6					
Pipes	4	-28%	4%	20%		
Soil and Land	40	-18%	3%	10%	2%	18%
Tillage	26					
Zero tillage	25	-14%	6%	8%	2%	14%
Levelling	14					
Field levelling	14	-23%	-2%	15%	3%	52%
Grand Total	**240**	**-32%**	**-4%**	**13%**	**20%**	**37%**

Note: Green denotes desirable changes (decreases in irrigation and evapotranspiration; increase in yield and water productivity); red is used to denote undesirable changes.

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Guidance on realizing real water savings with crop water productivity interventions

This technical document contains clear and practical guidelines on how to implement 'real' water savings in agriculture through interventions for enhancing crop water productivity. A distinction is made between real water savings and 'apparent' water savings. Apparent water savings record reductions in water withdrawals but do not account for changes in water consumption. Real water savings record reductions in water consumption and non-recoverable return flows (runoff or percolation). This guidance document emphasizes the paradox of water savings at field and basin scales, which usually do not translate into increased water availability for other users as is commonly believed.

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