FutureWater

FAO's Water Scarcity Program

Guidance on Realizing Real Water Savings with Crop Water Productivity Interventions

REPORT 198

CLIENT FAO

AUTHORS
Jonna van Opstal
Peter Droogers
Alexander Kaune
Pasquale Steduto
Chris Perry

DATE April 2020

Guidance on Realizing Real Water Savings with Crop Water Productivity Interventions

FAO's Water Scarcity Program

FutureWater Report 198

Client
FAO Regional Office for Asia and the Pacific

Authors
Jonna van Opstal (j.vanopstal@futurewater.nl)
Peter Droogers (p.droogers@futurewater.nl)
Alexander Kaune (a.kaune@futurewater.nl)
Pasquale Steduto (psqlsdt@gmail.com)
Chris Perry (chrisjperry@me.com)

Acknowledged contributors
Louise Whiting (louise.whiting@fao.org)
Hugh Turral (hugh.turral@gmail.com)

Date
April 2020

ADDRESS
FutureWater B.V.
Costerweg 1V
6702 AA Wageningen
The Netherlands

TELEPHONE +31 317 460 050
WEBSITE www.futurewater.eu

FutureWater

Executive Summary

This technical document is intended to serve as a clear and practical guideline on how to implement “real” water savings in agriculture by selecting suitable interventions for enhancing crop water productivity. A distinction is made in “real” water savings in contrast to “apparent” water savings. “Apparent” water savings report on 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 reports on reductions in water consumption and non-recoverable return flows (runoff or percolation). This Guidance document emphasizes the paradox between water savings at field and basin scale, which usually do not translate into increased water availability for other users (helping to dispel common myths in this area).

An intervention framework categorizes water savings interventions into three themes: water management, soil and land management, and agronomy. An inventory of publications lists information of each intervention regarding changes in irrigation water applied, water consumption (i.e. evapotranspiration), crop yield, and water productivity. The best interventions for achieving higher water productivity are mostly related 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 provides information on the expected changes at field scale for various interventions. The impact at a larger context requires an analysis at district level or basin scale. The ‘follow the water’ terminology introduces water accounting terms to communicate the categories of water flows in a system. Water Saved is the amount of water resulting from a reduction in consumption and/or in the non-recoverable fraction of the return flows, and that can be made available for alternative uses. Following the concepts and guidelines of this document, decision-makers can improve the management of their water systems to achieve “real” water savings and introduce interventions sustainably.

Table of Contents

List of Tables

List of Figures

List of Boxes

1 Introduction

1.1 Objective

This technical document is intended to serve as a clear and practical guideline on how to implement "real" water savings in agriculture by selecting suitable interventions for enhancing crop water productivity. A distinction is made in "real" water savings in contrast to "apparent" water savings. "Apparent" water savings report on 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 reports on reductions in water consumption and non-recoverable return flows (runoff or percolation). This Guidance document emphasizes the paradox between water savings at field and basin scale, which usually do not translate into increased water availability for other users (helping to dispel common myths in this area). The background and concepts are explained in Chapter 2 of this Guidance.
This Guidance will offer in parallel water savings options that can help agriculture become more productive without increasing water consumption. Crop and water management interventions are listed in Chapter 3, including the intervention framework adopted in this Guidance. Chapter 4 provides a summary of the inventory reference database listing 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 is developed for audiences ranging from extension services officers up to water managers and irrigation specialists designing and managing irrigation systems, and policy makers or river basin planners making 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 as the gap between water demand and supply is projected to increase by due to factors such as population growth and economic development (Dinar et al., 2019), and environmental factors such as land degradation (IPCC, 2019) and climate change (Turral et al., 2011). Solutions to reverse this trend should often focus on irrigated agriculture as irrigation is the largest consumer of freshwater withdrawals in almost all water-scarce regions. FAO has always played a leading role in finding agricultural solutions to manage water shortages.

Unfortunately, solutions to overcoming the water crisis by looking at the agricultural sector are not simple and have often led to unrealistic expectations. Misconceptions and overly simplistic (and often erroneous) views have been flagged and described over the last recent decades, but uptake of those insights by decision makers and irrigation sector has been limited. The most striking issue is that modernization of irrigation systems has, in many cases, led to increased water consumption, as opposed to the water savings that are often assumed to be delivered by irrigation modernization programs (e.g. 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 assumed water savings at the local level are in reality often limited at a basin scale context or even increased water consumption (Giordano et al., 2017).

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

2 Background and concepts on real water savings

It is commonly perceived that agricultural water users waste large quantities of water during the irrigation process and thus real water savings could reduce the need to construct additional facilities to tap more water (Molden et al, 2001). This perception is derived from common knowledge that on-farm irrigation application efficiencies are often in the order of 20 to 50 percent, implying that the remaining 80 to 50 percent is somehow lost. Typical examples of this thinking were reflected in various FAO publications from the past 30 years (Figure 1).

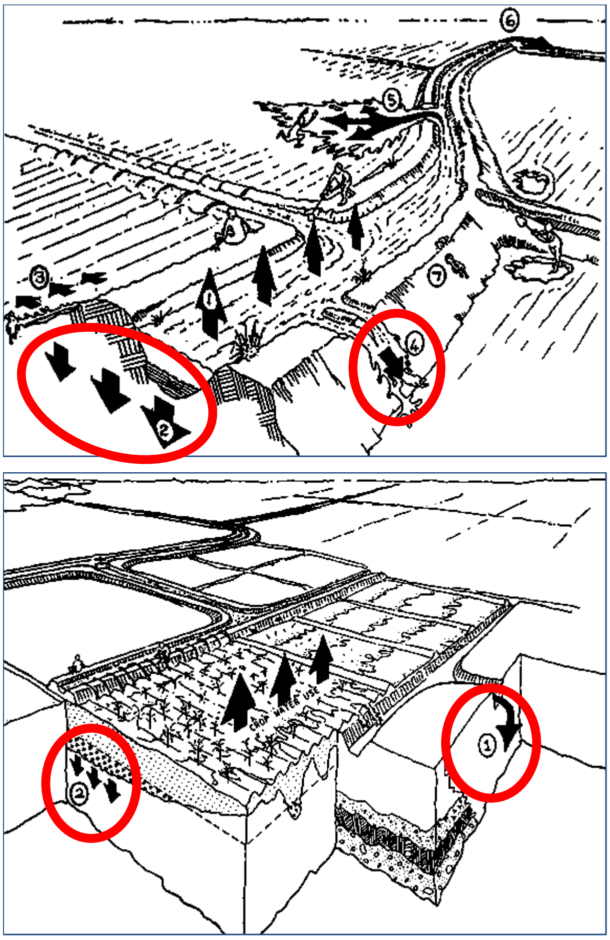


Figure 1. Last century perspectives on water losses. Original captions: Figure 24 shows the irrigation water losses in canals (top) and irrigation water losses in the field (bottom) to groundwater or surface runoff. Source: (Food and Agriculture Organizations (FAO), 1989a, 1989b)

The key misconception stems from the classical notion of "irrigation efficiency" as was 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 classical irrigation efficiency concept to water basins as a whole leads to incorrect decisions and, therefore, to faulty public policy (Keller and Keller, 1995). They continued stating:

"*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.*"

The scientific literature and expert reports and meetings on "real" water savings is growing rapidly. The term real water savings is used here to emphasize that the perspective of only looking at a field should be broadened to entire basin; in other words, we define a real water saving as an intervention that releases an identified quantity of water to an alternative use. Box 1 details the definitions of these concepts as are adopted in this publication. A recent review (Pérez-Blanco et al., 2020) mentioned 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 identified over found by them over a period of 42 years (1976-2017), some 91 (40.6%) were published in the last 9 years (2010-2018).

BOX 1. 'Follow the Water' Terminology

Water Use is the amount of water applied for a specific purpose (e.g., irrigation, power station, industrial processes, domestic washing, etc.).

Any *Water Use* can be either *consumed;* or *returned* to the system where it has been applied; or be *stored*.

The water *consumed* can be either *beneficial* (e.g., consumed as crop transpiration) or *non-beneficial* (e.g., consumed as soil evaporation).

The water *returned* to the system (*return flows*) can be either *recoverable* (e.g., returning to a river or to an aquifer) or *non-recoverable* (flowing to the sea or other 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*, and that can be made available for alternative uses.

Water Saving refers to the technologies, practices and measures (here overall indicated as *interventions*) leading to the above-mentioned *reduction* in *consumption* and/or in *non-recoverable* fraction.

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

A second important aspect in the context of water savings is the correlation between crop evapotranspiration and yield. It is reported that yield is linear related to crop transpiration under the conditional constraint that "everything else being equal" (Perry and Steduto, 2017). Especially in Asia with its wide diversity in irrigation practices, crops, and crop management many options for real water savings might be possible.

(Perry and Steduto, 2017) noted: "*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).*" And they continued noting that the near linear function between yield and crop transpiration, is "*derived for 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 short, simply increasing the supply will increase *production* (kg) but will not increase by *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 those water-agronomy aspects where real water savings are possible, or higher production can be achieved with the same amount of (evapo)transpiration.

This non-linearity between crop evapotranspiration and yield can be substantial considering a wide-range of climate, agro-economic zone and farm management practices. Figure 2 indicates that with the same amount of evapotranspiration ranges in yields can differ a factor of five. Box 2 elaborates further on the connection between water savings interventions and water productivity.

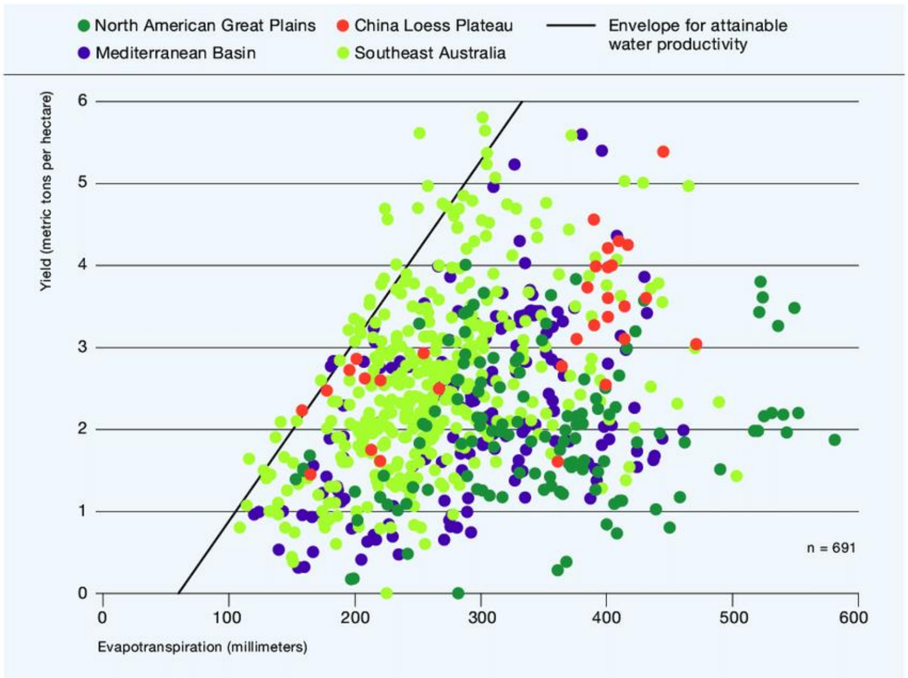


Figure 2. Variations in the water productivity of wheat (kg/ha/ET) in different regions. Source: (Giordano et al., 2017) based on (Molden, 2007)**.**

BOX 2. Does increased water productivity save water?

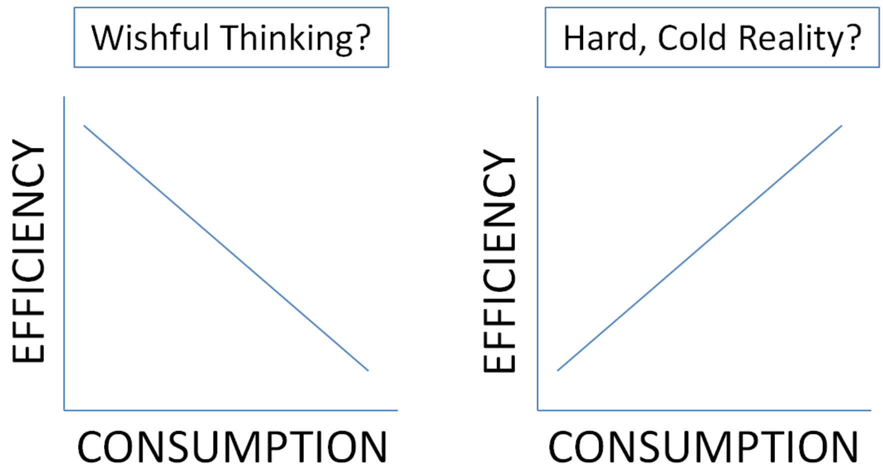
Interventions that increase water productivity (defined as the water consumed in producing a crop), are frequently assumed to save water, on the grounds that the same quantity of crop can be produced with less water. This assumption is only true if the water allocation is reduced when the intervention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

The parallel case of increasing land productivity (kg/ha) is more easily understood: if a farmer can grow 20% more crop per hectare with a new variety, we do not then 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.

This impact is doubly effective 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 and so 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 the water consumption increases.



Besides this paradigm shift in agricultural water management from a local irrigation efficiency perspective towards basin scale assessments another important aspect should be considered: water savings. It may seem obvious that water savings are generally considered as positive, but the important question that needs to be asked is what happens to the saved water and at which (temporal and spatial) scales should this be assessed. Perry (2020, personal communication) proposes the following definition for water savings:

“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, aiming at water savings is probably not needed. One could add to the definition that the alternative beneficial use should have a higher priority and/or higher water productivity compared to the original use. Priority is often determined by decision making processes between sectors (e.g. agriculture vs environment), while water productivity is more used to compare use within one sector (e.g. irrigated vegetables vs. irrigated rice). For the latter extensive research and literature on water productivity (expressed as kg per cubic meter water consumption, or US$ per cubic meter water consumption) can be found.

Moving from an on-farm perspective to a basin perspective, it is often found that, because of reuse of “lost” water, much less water is “lost” than commonly perceived. From a hydrology perspective this is common knowledge and referred to as the water cycle: water is never lost. In the irrigation science this “follow the water” concept started around the year 2000 and is often referred to as water accounting. A typical example of this approach is shown in Figure 3.

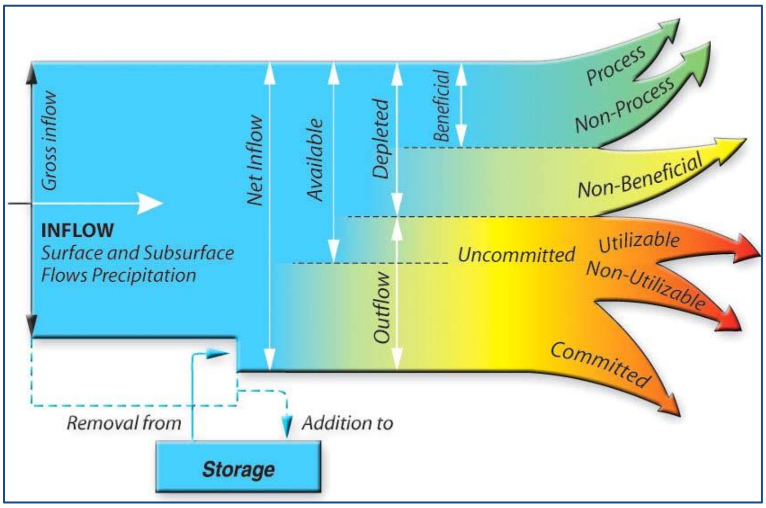


Figure 3. Water accounting framework for irrigated agriculture. (Molden et al., 2001)

Many efforts to improve and enhance water accounting frameworks have been proposed. In all those efforts refinements were made resulting in an additional level of complexity for which data were often lacking to make those useful. Moreover, this additional level of complexity 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 focussing on four main components of the water flows. Perry (2007) simplified the approach to four main components to ensure that focus would be on the main components of those water flows. In this report this approach will be used and will be referred to as “Follow the Water” and is shown in Figure 4. The main concepts are that water diverted to irrigation schemes can be divided into the following components:

- The consumed fraction (essentially ET), comprising:
    - beneficial consumption (for the purpose intended or other beneficial use such as environmental purposes);
    - non-beneficial consumption (such as 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 (percolations to saline aquifers, outflow to drains that have no downstream diversions or direct outflow to the ocean).

The inventory on water savings techniques as described in Chapter 4 and the guidelines with practical intervention (Chapter 3) are based on this “Follow the Water” approach.

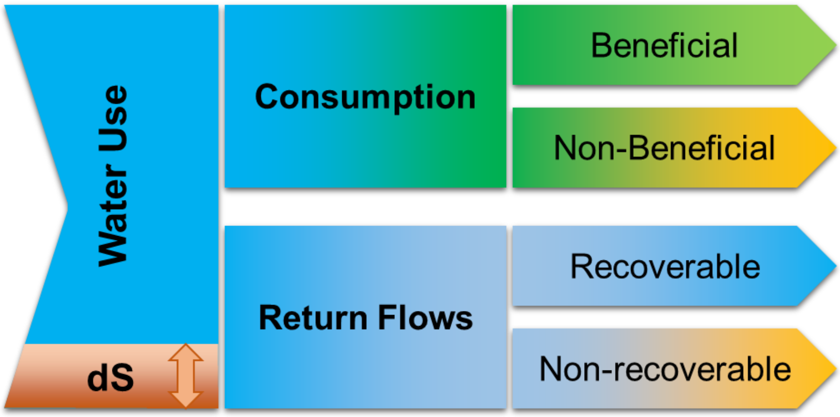


Figure 4. Simplified water accounting system referred to as “Follow the Water”, with dS representing delta (i.e. change) of water stored

3 Crop and Water Management Options in Irrigated Agriculture

3.1 Introduction

The necessity to improve crop and water management have been called upon in many studies and reports. However, the majority of those reports are limited to emphasizing the importance of optimizing crop and water management without actually providing guidelines on how to achieve this. On the contrary, the scientific literature describes many detailed studies on a rather small and location specific component of optimizing crop and water management.

A second challenge in developing those guidelines is to develop a structured framework where broader options can be derived into smaller ones. No universal categorization in options exists as this depends on the overall objective. Some typical options and categories relevant for this particular guidance will be summarized here.

FAO 36

A FAO study on adaptation to climate change (Turral et al., 2011) includes an interesting overview that goes beyond adaptation to climate change only, but can be used as an overall framework on improving crop and water management. The framework consists of the following categories and sub-categories:

- 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 sub-sector
  - Mechanisms for allocation
  - National food policy issues
- Institutions
- Long-term investment implications for agricultural water management

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

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

Aerts, Droogers, 2004

Similarly, it was reported (Aerts and Droogers, 2004) that two main groups of options at farm level exists to focus on:

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

FAO 38

The FAO report "Coping with water scarcity: An action framework for agriculture and food security" (Food and Agriculture Organizations (FAO), 2012) made it very clear that changes are needed. In the water policy domain:

- 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 following options were described in FAO 38:

- 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. (Food and Agriculture Organizations (FAO), 2012)

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

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

Perry et al., 2009

In the landmark[1] paper of Perry, Steduto, Allen and Burt they discussed "Increasing productivity in irrigated agriculture: Agronomic constraints and hydrological realities" (Perry et al., 2009). Although the study focuses mainly on getting terminology and thinking about water savings in a proper perspective, they also discussed crop and water management options available to farmers. They argued that there is no simple answer to the question ‘‘which irrigation method is best?’’ Moreover, they 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." Choices made by farmers depend on:

- Increased income: if yield tonnage, quality, or alternative, high value crops will more than adequately pay for investment, there is an incentive to improve.
- Risk aversion/food security: Farmers may shift from rainfed agriculture to irrigation to reduce the uncertainties associated with variable rainfall patterns. Similarly, farmers may shift from public, surface-delivery systems to well water because the surface water is delivered in an inflexible and unreliable manner.
- Convenience: This is primarily seen in commercial farming. As an example, a farmer may not want to have to wake up in the middle of the night to receive project water deliveries, or he may be able to deliver fertilizers more precisely and cheaply through ‘‘fertigation’’ systems.
- Reduced costs: A farmer may save pumping costs if delivery losses are reduced; he may save labor by installing equipment that does not require constant field presence.
- Non water related motivations: Saving labor, growing higher value crops, reducing uncertainty, cost, credit availability, extension advice, technical support, land leveling, amongst others

APAN[2]

The Asia Pacific Adaptation Network has developed an Adaptation Technology Database in which 10 categories were defined and each category has a subset of technologies. The most 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

[1] 152 citations according to Science Direct (Dec-2019)
[2] http://www.asiapacificadapt.net/adaptation-technologies/database

The total number of technologies is still limited and it is unlikely that the database is still updated (last update was from 2015). The approach taken in this project is however quite interesting as each of the technologies has the following descriptions:

- Technological Maturity
- Applicable immediately
- Technology Owners
- Cost
- Ease of Maintenance
- Technology Performance
- Co-benefits,
- Suitability for Developing Countries

ADB, 2020

A so-called "good practice guide" for Supporting Adaptation Decision Making for Climate-Resilient Investments in the waters sector (Droogers and Carpenter, 2020) includes some interesting criteria to be used to evaluate the various adaptations. Although those criteria are specifically focused towards climate change adaptations, some of those are relevant to be used in this guidance:

- 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 eg carbon sequestration, job creation
  - *Limited, Medium, High*
- Barriers to Implementation – degree of complexity eg multi-country agreements
  - *Easy, Medium, Difficult*
- Capacity Required to Implement – extent of specific eg 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, Hrast-Essenfelder, Perry, 2020

This study (Pérez-Blanco et al., 2020) examined 230 empirical and theoretical papers on water conservation technologies (WCT). The conclusion of the review is that WCTs should not be regarded as a way to achieve water conservation, but rather as a means of stabilizing and enhancing agricultural water productivity and farmers' income where water is scarce.

The study makes a strong distinction between those WCTs and WCPs (water conservation policies) and argue 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 rather than new *technologies* only.

In the context of this guidance, the 230 reported interventions were further examined and filtered and categorized. Many of the reported technologies had an objective to achieve "increased efficiency" as a means of saving water, but in most cases this related only to field-scale levels to reductions in water applications.

Interestingly, this review study hardly addressed agronomic aspects, and is limited to two categories of interventions: "alternate wetting and drying" and "deficit irrigation". This emphasizes again the need to include agronomy technologies as summarized by (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 near linear function between yield and crop transpiration, is derived for specified and consistent package of crop husbandry (planting date, cultivar, planting density, fertilization status, soil, etc.) with only water input being varied."

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**

IWMI Research Report 169

The International Water Management Institute (IWMI) initiated a rethinking on irrigation water efficiencies under the phrase: "The new era of water resources management: From "dry" to "wet" water savings". The report outlined several key ideas that fundamentally changed a research paradigm from one that focused on ‘irrigation efficiency’ and ‘performance of irrigation systems’ to one centred on ‘water productivity’ and ‘river basin management’.

The IWMI Research Report 169 (Giordano et al., 2017) summarizes a framework to achieve real water savings. The publication mentioned four main intervention groups, with for each group some typical examples:

- (i) Increase yield per unit of water consumed by, for example:
    - improving water management by providing better timing of 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.
- (ii) Reduce non-beneficial depletion by, for example:
    - increasing the proportion of water applied that is used beneficially by crops, by (a) 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 (b) 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.
- (iii) 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.
- (iv) 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 as described in the previous section have been used to derive a practical hierarchal setup for the interventions described in this Guidance. The setup is simple and consists of three levels: theme, category and intervention. Each intervention describes the potential to enhance crop and water management. The term “enhance” is used here as the overall aim is to increase water productivity at basin scale and/or reduce water consumption to support downstream water users.

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

Interventions regarding an 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 productivity per unit land.

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	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 as presented in section 3.2 of this document provides a framing for three themes - water, soil/land and agronomy - and the underlying categories and interventions for each. Based on this framework an inventory was made to quantify the impact each intervention has on water management and productivity. A literature review was conducted to note results from scientifically peer-reviewed articles, technical documents, and other publications. This chapter provides a summary of the inventory and the main findings.

4.1 Inventory database structure

The list of references included in the inventory is provided in Annex 1. The inventory reported findings according to the following structure.

Publication type

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

Countries and climate zones

The focus of the literature review was on countries in the Asia and Pacific region. Other countries were included if the climatic conditions are similar to several countries in Asia and Pacific region, for example the Mediterranean and Western USA. Distinction was made in climate zones for 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 in the publication). These varied from field experiments, farmers surveys, measurements for a block of fields and district level, and simulation models at field, district and hydrological levels.

Reported changes

Publications were included that could indicate a change in water volumes or crop production due to an implemented intervention. These changes were quantified as percentages of change compared to 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 (if mentioned)
- Crop yield
- Water productivity: yield per unit of evapotranspiration (water consumed)
- Irrigation water productivity: yield per unit of irrigation (water applied)

4.2 Summary inventory findings

An overview of the inventory and reported changes is presented in Table 2. For each intervention under the specified theme and category, the average changes in each aspect is presented. In addition, the number of studies used for computing the average is indicated in the 'count' column. Interventions with two or fewer publications are excluded from the table. A total of 240 studies are used of which 131 for water management, 40 for soil and land management, 54 for agronomy, and 15 other interventions that were not included in the intervention framework (irrigation scheduling, raised beds, etc.).

Table 2 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 is used for "desirable" changes (decrease in irrigation, evapotranspiration; increase in yield and water productivity); red is used for "undesirable" changes.

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 if "real" water savings are achieved. Increases in crop yield, water productivity (per unit of ET) and irrigation productivity (per unit of irrigation) are coloured green.

For the agronomy and water management themes the average result is that both reductions in irrigation and evapotranspiration can be achieved whilst simultaneously resulting in a higher crop yield and water productivity. Agronomic practices logically achieve a higher increase in yield on average (of 19%) and water management achieves a higher reduction in irrigation (38%); the reduction in evapotranspiration is similar for both themes. For soil and land management interventions the evapotranspiration slightly increased (3%).

The number of publications reporting increases or decreases are shown in Table 3 for each intervention.

Table 3 Inventory summary with indicating number of publications reporting increases or decreases in irrigation, evapotranspiration (ET), crop yield and water productivity (WP) for various field interventions.

			# of publications reporting an increase (↑) or decrease (↓)								
Theme	**Category**	**Intervention**	**Irrigation** ↑	**Irrigation** ↓	**ET** ↑	**ET** ↓	**Yield** ↑	**Yield** ↓	**WP** ↑	**WP** ↓	**# of publications**
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			9	2	3	5	6	1	3	15
										TOTAL	240

4.3 Top (and bottom) lists for interventions

For each aspect (irrigation, evapotranspiration, yield and water productivity) the top and bottom five interventions are listed in Table 4. These are independent of other factors (number of studies, crop type, irrigation method, climate zone, or country), but are based on the average of all studies as listed in Table 2, excluding interventions with two or fewer publications in the inventory.

The top five interventions for reducing water applied (or irrigation) are all water management related (in blue). Notably, regulated deficit irrigation results in a reduction of irrigation and also evapotranspiration. However, deficit irrigation ends in 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 several water management interventions, namely sub-surface irrigation and conversion to pipe irrigation distribution systems (instead of open canals). Note that pipe distribution

system is an intervention implemented at a district (or sub-unit) level. This will require more investment and cooperation of farmers but can result in higher returns in crop yield.
Crop rotation is listed as one of the top 5 interventions to reduce evapotranspiration. However, it is placed in the bottom 5 for both yield and water productivity. By changing the crop rotation less crops are grown, which has a larger impact on yield than on reducing evapotranspiration, as indicated by the water productivity.

Chapter 5 elaborates further on descriptions of each intervention indicating its relevance at which spatial scale and other details. In practice, there are various incentives for decision-makers to implement interventions. Box 3 elaborates further on the perspectives of decision-makers, and possible incentives at farmer level to implement interventions.

Table 4 Overview of top 5 and bottom 5 interventions for reductions in irrigation or water applied, and evapotranspiration (ET), or increases in 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 % change due to the intervention as averaged in Table 2.

BOX 3. From reported water savings to practical implementation
– What drives decision-makers to change? –

Farmers are interested in increasing their reliable income. The various technologies described assist a farmer to increase production when water is scarce. We know little about actual cost/benefits, so all we can say are that as water becomes scarcer, these are interventions they can consider. Adoption of these interventions will depend on the amount of risk involved. Trade-offs are made in business-like fashion balancing the economic risks and potential profits.

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

Neither of these two groups has any interest in "saving" water, except to be able to increase beneficial consumption.

Scheme Managers may be interested in these interventions if there is shortage at tail ends, 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 of the report provides guideline on the interventions: background, details on implementation, suitability and potential impact on field scale and basin scale water issues. Since interventions are always location specific (climate, socio-economic context, political preferences, governance mechanisms, etc.) the interventions should be considered as a menu of options for consideration, rather than a rigid guideline.

The interventions are based on the framework as defined in Chapter 3. Chapter 4 describes the actual reported interventions. The 32 interventions described in this section are based on the previous Chapters added with a mixture of scientific literature, reports, websites, and experiences. Expert knowledge has been used to combine all those sources and exact referencing has not been possible. Referenced justification is given in Chapter 4.

The interventions are grouped in the following three themes: water management, soil and land management, and agronomy.

Border/furrow irrigation		
Theme: Water	*Category:* On-field irrigation	
Overview: Traditional irrigation practices in which water is brought to the field from canals or pumped from the 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: • High amounts of return flows		
Details: Border and furrow irrigation are amongst the most traditional irrigation methods and applied widely. Border irrigation is generally best suited to larger fields with deep homogenous loam or clay soils with medium infiltration rates. Mainly applied to close growing crops such as pasture or alfalfa. Furrow irrigation consist 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 systems from canals and/or pumping from groundwater. Reported irrigation efficiencies are in the range of 40% to 70%. Focus should be on reuse by downstream users so minimizing non-recoverable return flows.		

Sprinkler irrigation		
Theme: Water	*Category:* On-field irrigation	

Overview: Irrigation is applied using sprinkler systems for which pumping is needed to have 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 be applied at lower application rates • Non-beneficial consumption by evaporation from wind losses • Reduced drainage, runoff and percolation		
Impact at basin scale: • Reduced amount of return flows (potential impact on third-party users) • Lower irrigation demands • High reliable irrigation supply system needed		
Details: Sprinkler irrigation is a method of applying irrigation water which is similar to natural rainfall. Water is distributed through a system of pipes by pumping. The pump supply system, sprinklers and operating conditions must be designed to enable a uniform application of water. 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 sensitive to developing crusts. Sprinkler systems are often chosen for their higher irrigation efficiency. Return flows are in general lower compared to basin, border and furrow irrigation systems. However, systems that are converted to sprinkler see often a remarkable increase in water consumption, while reductions in water intake (i.e water quotas) are 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 for which 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 be applied at 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 (potential impact on third-party users) • Lower irrigation demands • Very high reliable irrigation supply system needed		
Details:		

Drip irrigation involves dripping water onto the soil at very low rates from a system of small diameter plastic pipes fitted with outlets called emitters or drippers. Water is applied close to plants so that only 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 (usually every 1-3 days) than with other methods and this provides a very favorable high moisture level in the root zone of the soil.

Drip irrigation systems are often chosen for their higher irrigation efficiency. Return flows are in general very low. However, systems that are converted to sprinkler see often a remarkable increase in water consumption, while reductions in water intake (i.e water quotas) are often not established or accepted by farmers, ruslting in an overall increase in water consumption at the basin scale.

Sub-surface irrigation

Theme: Water	*Category:* On-field irrigation	

Overview:

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

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 be applied at very low application rates and high frequency
- Very much reduced drainage, runoff
- Salinity risks without leaching by rainy season

Impact at basin scale:

- Very low return flows (potential impact on third-party users)
- Lower 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 ranged from 0.02 to 0.70 m and lateral spacings ranged 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 non-beneficial consumption (evaporation from soil and irrigation water) will be minimized.

Drip irrigation systems are often chosen for their higher irrigation efficiency. Return flows are in general very low and mainly restricted to groundwater recharge (especially during the start of the season when roots are not well developed). However, systems that are converted to sprinkler see often a remarkable increase in water consumption, while reductions in water intake (i.e water quotas) are often not established or accepted by farmers, ruslting 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 (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 in which irrigation is applied during drought-sensitive growth stages of a crop. Outside 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 have often the knowledge of sensitive stages of their crop. Reliability of water supply is key to success. Expected level of impact depends on the "intensity" of the supplemental irrigation (e.g. 90%, 80%, 70% of crop water requirements).		

Surge irrigation		
Theme: Water	*Category:* On-field irrigation	
Overview: Surge irrigation is the intermittent application of water aiming at improving 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 (potential impact on third-party users)		
Details: Surge irrigation is the intermittent application of irrigation water (5-10 minutes) used to improve distribution uniformity along a furrow. It works on the principle that dry soil		

infiltrates water faster than wet soil. When soil is wet is seals because the soil particles at the surface consolidate. When water is re-introduced 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 phenomena allows for a faster advance through the field with less deep percolation and better application uniformity. The end result is a more even distribution of water in the rooting zone and reduced deep percolation.

Surge irrigation is performed through a program of cycle times (on-off) that account for the advance of the furrow (normally 5-10 minutes). The intermittent application reduces the tail water 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 tail water leaves the furrow.

Surge flow irrigation can be successfully implemented on clay and cracking clay soils and clay loams - using borders as well as in 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 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 based on 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 (potential impact on third-party users)

Details:

Alternate wetting and drying (AWD) is a water management technique, practiced to cultivate irrigated lowland rice and differs from the usual system of maintaining continuous standing water in the crop field. It is 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 as no buffer in the field is available. Also increasing 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 (potential impact on third-party users)		
Details: Seepage flows can be 30 to 50 percent of 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 at system scale by lining are in many cases 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.		

Pipes		
Theme: Water	*Category:* Irrigation infrastructure	
Overview: A pressure 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 (potential impact on third-party users)		
Details: A pressure piped irrigation system is a network installation consisting of pipes, fittings and other devices properly designed and installed to supply water under pressure from the source of the water to the irrigable area. The pipelines that convey and distribute the		

irrigation water to the individual plots are usually buried, and are so protected from farming operations and traffic hazards. Offtake hydrants, rising on the surface, are located at various spots according to the planned layout. With surface methods the irrigation water can be delivered directly to the open ditches feeding the furrows or the basins.

Pipes are a prerequisite for sprinkler and drop irrigation as pressure is needed.

In a pressure 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, 2–3 bars, which is provided from a pumping unit or from 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 of saving water, protecting the environment and supplying food

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 by moisture recycling

Impact at basin scale:

- Reduction in return flows (potential impact on third-party users)
- Lower application demands

Details:

Protected agriculture in the form of greenhouses is an agricultural production system mainly suited for dryer conditions and expensive marketing crops (vegetables, flowers). The system requires low amount of water by moisture recycling. Greenhouses can yield up to five times the land productivity and seven times the water productivity of open cultivated lands. They provide food safety and high 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 investment and sophisticated knowledge is essential.

Hydroponics

Theme: Water	*Category:* Moisture recycling	

Overview:

Hydroponics and hydroculture does not require soil and is mainly practices in protected agriculture (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 (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 growing medium (or inert). The inert growing medium is usually rock-based, typically something called expanded clay aggregates. Hydroponics and hydroculture require in general somewhat less water as return flows are very low. Also nutrients and chemicals can be supplied in a very precise amount.		

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 amount of non-beneficial consumption by weeds		
Impact at basin scale: • Lower water availability		
Details: Zero till farming decreases the amount of soil erosion 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 into the soil, soil retention of organic matter, and nutrient cycling. These methods 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 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 in general high, driven by the large amount of weeds.		

Tillage

Theme: Soil and Land	*Category:* Tillage	
Overview: Tillage is the agricultural preparation of soil 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: • Soil depending		
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, incorporate crop residues, kill weeds, and to aerate the soil. Secondary tillage is any subsequent tillage, in order to incorporate fertilizers, reduce the soil to a finer tilth, level the surface, or control weeds In general tillage will destroy weeds (and breaks the capillary raise, generating a mulching effect and redcuing non-beneficial consumption), dries the soil, impacts infiltration capacity, loosens soil so increases water storage capacity, among other impacts. However, soil type is a major factor in which way those processes will take place.		

Field levelling

Theme: Soil and Land	*Category:* Land grading	
Overview: Field leveling is a process for ensuring that the depth and discharge variations over the field are relatively uniform and, as a result, that water distributions in the root zone are 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 leveling has two distinct forms. During construction or rehabilitation of irrigation systems fields will be leveled and large amount of soil transportation is normally involved in order to create leveled fields. The small-scale leveling is performed by farmers regularly (every year) to recuperate the land from farming and tillage.

Levelling, smoothing and shaping the field surface is 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 irrigation advance in surface irrigation (border, basin, flood) and therefore, if flow rates and times are managed properly, the irrigation uniformity should be higher and deep percolation and drainage should reduce 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, which resemble 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 terrace steps are commonly used to farm on hilly or mountainous terrain. Terraced fields decrease both erosion and surface runoff, and may be used to support 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: 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 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 to the two types of terraces. The irrigation or level bench terraces are used where crops, such as rice, need flood irrigation and impounding water. The upland bench terraces are used mostly for rain-fed crops or crops which 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: All	*Crop Type:* All	*Scale:* Field
Consumption Beneficial: varies	*Consumption Non-Beneficial:* Lower	*Return Flow:* varies
Impact at field scale: • Enhanced crop growth and higher water productivity		
Impact at basin scale: • Higher water productivity		
Details: Nutrients help maximize the amount of water used productively. Water is consumed in crop fields either through productive transpiration or non-productive soil evaporation. Evaporation of water from the soil is reduced when the surface is shaded under the crop canopy, leaving more water available for plant transpiration. Well-fertilized and healthy crops have more vigorous and extensive roots 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 fertilizer. Good early nutrition improves crop competiveness. A crop 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 enhancer (or plant growth regulators, PGR's) have varied effects on 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: Plant growth regulator (PGR) is a term that 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 the crops. Very small doses are required. PGRs are not yet widespread, but according to varies studies these can become very important in influencing all kind of plat processes such as drought resistance, higher yields, faster leave development amongst many others. There exist a quite diverse range of PGRs and need additional research. PGRs have the potential to increase water productivity substantially.		

Crop rotation		
Theme: Agronomy	*Category:* Crop selection	
Overview: Changes in crops, cropping patterns and crop rotations.		
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: Crops grown and cropping patterns/rotations is probably the most determining factor in water consumption, water productivity and economic return. A typical example is to replace high water consuming crops (e.g. rice, sugarcane) for less water consuming crops. Obviously, not only water is the driving force for changes, but economic returns are in most cases driving the decisions. Also farmers' knowledge and cultural food preferences should be considered.		

Cultivars: high yields

Theme: Agronomy	*Category:* Crop selection	
Overview: Us of crop cultivar 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 • Higher 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 to maintaining adequate food supplies (green revolution). Advances in genetics and genomics have fostered a better understanding of crop function and has 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 an integrated breeding approach. Genetic modification can lead to high-yielding cultivars, although acceptance by the public varies. Dependency on seed suppliers is another point of contention. The overall impact of high yielding varieties on water can be diverse. In some cases more water will be consumed by crop transpiration, in parallel with increases in water productivity.		

Cultivars: short duration		
Theme: Agronomy	*Category:* Crop selection	
Overview: Use of crop cultivar with a shorter 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 led to crop varieties that have shorter growing seasons. For many crops those improved cultivars are available and typical examples include rice, wheat and maize. Most of those varieties have been selected on their "dwarf" characteristics, where the fraction of stem and leaves over storage organs has improved. The overall impact of short duration cultivars is lower crop transpiration without severe impact on yield. So both water is saved and water productivity is higher.		

Cultivars: rooting depth		
Theme: Agronomy	*Category:* Crop selection	
Overview: Use of crop cultivar with a deeper rooting system.		
Climate zone: All	*Crop Type:* All	*Scale:* Field
Consumption Beneficial: Higher	*Consumption Non-Beneficial:* Neutral	*Return Flow:* Lower
Impact at field scale: • Lower irrigation demand		
Impact at basin scale: • Reduced return flows (potential impact on third-party users) • Lower water demand		
Details: Cultivars have been developed that have a deeper and better developed rooting system. Those cultivars are sometimes marketed as drought resistance varieties as they have the ability to draw water from deeper soil layers. From a water consumption perspective those varieties will increase consumed water, leaving less water for percolation and/or drainage. 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 requires proper impact analysis at basin level.		

Timing of planting / sowing		
Theme: Agronomy	*Category:* Crop selection	
Overview: Optimizing planting or sowing date of crops to make better use of water resources.		
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: It is evident that planting or seeding should be done at the right moment to benefit from the best climate (rainfall, temperature, sunshine) conditions. However, in some cases this is not practiced by various reason. Important one is that prices for harvested products is often higher outside the traditional harvesting season. Other reasons are often related to farmers' habits, labor shortage, and/or lack of seasonal forecasting. Impact of optimized timing of planting/sowing on water consumption depends on the actual implementation of this intervention. In general somewhat more water will be consumed and water productivity might be higher or lower.		

Planting density

Theme: Agronomy	*Category:* Crop selection	
Overview: Changes in planting density, either higher or lower density can be considered.		
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 as soil fertility, labor, machinery, and climate. In some cases lower planting density can be effective in capturing more rain per plant and/or reducing irrigation demand. Higher planting density can be very effective in reducing soil evaporation and non-beneficial water consumption by weeds.		

Mulching

Theme: Agronomy	*Category:* Coverage	
Overview: Covering the soil by mulch material either by crop residues, material brought to the field (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: A mulch is a layer of material applied to the surface of soil. Reasons for applying mulch include conservation of soil moisture, improving fertility and health of the soil, and/or reducing weed growth. Mulch can be organic or artificial. Organic mulch is in many cases achieved by tillage of remains of the previous crop. In some cases organic material such as bark chips and straw will be brought on the field. Plastic sheeting is especially in China widespread applied. Many experiments have reported substantial water savings and options to expand the growing season (earlier) by temperature regulation.		

From a water savings perspective mulching can be very effective. Climate zone, soil conditions, labor availability and costs are important considerations for applying this intervention.

Shading

Theme: Agronomy	*Category:* Coverage	
Overview: Interventions aiming at achieving less sunlight 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: Shading of crops can be achieved by covering fields with net or by planting higher crops/trees compared to the primary crop. Shading will result in protecting plants from high temperatures and therefore excessive evaporation to decrease their internal temperatures. Soil evaporation will also be reduced. In cases where shading is obtained by higher crops and especially trees water consumption of the entire field might increase. Proper analysis of benefit/cost of this type of shading is essential. Shading by nets might be expensive and labor intensive.		

Weed control

Theme: Agronomy	*Category:* Coverage	
Overview: Weed control can be achieved by chemical, mechanical, crop management or 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: Weed control encompasses many control methods. Often successful weed control requires the combination or sequential use of several methods (referred to as integrated weed management). Main control options: manual, mechanical, crop management, grazing, biocontrol, herbicides, prescribed fire, solarization, flooding, and other, more novel, techniques.		

The overall objective of weed control is to reduce competition with crop requirements (water, space, nutrients, sun). The actual “savings” in water might be small, as the crop that replaces the weed also consumes water. However, water productivity enhancement can be achieved as a shift from non-beneficial consumption to beneficial consumption can be achieved.

Cover crops		
Theme: Agronomy	*Category:* Coverage	
Overview: A cover crop is grown primarily for the benefit of the soil rather than the 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:		
Details: A cover crop is a crop of a specific plant that is grown primarily for the benefit of the soil rather than the crop yield. Cover crops are commonly used to suppress weeds, manage soil erosion, help build and improve soil fertility and quality, control diseases and pests, and promote biodiversity. Cover crops are typically grasses or legumes but may be comprised of other green plants. Most often, a cover crop is grown in the off-season before the field is needed for growing the cash crop. In essence, a cover crop readies the land for an incoming cash crop. Cover crops reduce the amount of water that drains off a field and can enhance groundwater percolation. In parallel, 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: Protecting the crop by using 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 diseases is a wide-spread practice. The result is that the crop survive pest and diseases so that yields can be obtained. The impact of pesticide use on water productivity is that the chances of yield losses due to pests and diseases is reduced, thereby achieving higher yields.

Biological		
Theme: Agronomy	*Category:* Disease control	
Overview: Protecting the crop by applying 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 or organic plant protection is the control of pests and diseases in a crop through the introduction of natural enemies of the harmful organisms, biological plant protection products and plant protection products of natural origin. A wide range of biological crop protection exists such as biological pesticides (biopesticides), natural enemies, pheromones, and signal rollers, amongst others. The impact of pesticide use on water productivity is that the chances of yield losses due to pests and diseases is reduced, thereby achieving higher yields.		

Leaching		
Theme: Agronomy	*Category:* Salinity management	
Overview: Apply water so that salts are leached 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 of saline lands implies removal of excess salts from arable and subsurface soil horizons by flushing water. Primary salinization develops by plant and soil		

evapotranspiration where only water is removed and salt remains. Secondary salinization happens if saline groundwater is reaching the root zone.

Leaching can happen naturally if rainfall is high during a season. In other cases farmers have to irrigate more than the actual crop water requirements. Important is that a extensive drainage system is needed to drain the saline water to the sea or evaporation ponds. Obviously, large quantity of water are needed that cannot be reused.

Salt-tolerant crop types		
Theme: Agronomy	*Category:* Salinity management	
Overview: Us of crop cultivar 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:

Crop breeding has developed crop varieties that can withstand salinity better.
Considerable improvements in salt tolerance of important crop species have been achieved in the past two decades for crops as barley, rice, pearl millet, maize, sorghum, alfalfa, and many grass species. Those achievements were mainly obtained using traditional breeding programs. 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

Realizing “real” water savings is complex and context specific. This Guidance provides information on the expected changes at field scale for various interventions. The impact at a larger context requires an analysis at district level or basin scale. The “follow the water” terminology introduces water accounting terms to communicate the categories of water flows in a system. Following the concepts and guidelines of this document, decision-makers can improve the management of their water systems to achieve “real” water savings and introduce interventions sustainably.

The inventory lists interventions that lead to increases in water productivity and reductions in water consumed. Several interventions, mainly related to water management and irrigation, are commonly promoted as water savings technologies but using this approach show that reductions in water consumption are limited. This Guidance urges decision-makers to adopt the approach of this document and analyse the overall context using the “follow the water” categorization. Saving water is solely achieved through reductions in water consumption and non-recoverable return flows.

A training tool (REWAS) is developed under this Guidance, to assist the decision-makers in adopting the approach of this Guidance into practical terms. Application of tools need to be expanded to translate the theory of this Guidance into practice. Farmers, being the ultimate change-makers, currently have limited incentive to adopt this approach. It requires a wider audience to continue this work and promote sustainable implementation of water productivity interventions.

References

Adamson, D., Loch, A., 2014. Possible negative feedbacks from “gold-plating” irrigation infrastructure. Agric. Water Manag. 145, 134–144. https://doi.org/10.1016/j.agwat.2013.09.022

Aerts, J.C.J.H., Droogers, P., 2004. Climate change in contrasting river basins: adaptation strategies for water ... CABI, Wallingford UK. ISBN: 9780851998350. 288pp.

Dinar, A., Tieu, A., Huynh, H., 2019. Water scarcity impacts on global food production. Glob. Food Sec. 23, 212–226. https://doi.org/10.1016/j.gfs.2019.07.007

Droogers, P., Carpenter, C., 2020. Supporting Adaptation Decision Making for Climate-Resilient Investments: Good Practice Guide. Asian Development Bank (ADB).

Food and Agriculture Organizations (FAO), 2012. Coping with water scarcity An action framework for agriculture and food security, FAO Water Reports 38.

Food and Agriculture Organizations (FAO), 2011. The state of the world’s land and water resources for food and agriculture. Food and Agriculture Organization of the United Nations, Rome and Earthscan, London.

Food and Agriculture Organizations (FAO), 1989a. Irrigation Water Management: Irrigation Scheduling.

Food and Agriculture Organizations (FAO), 1989b. Irrigation Water Management: Irrigation Methods.

Giordano, M., Turral, H., Scheierling, S., Treguer, D., McCornick, P., 2017. Beyond “More Crop per Drop”: evolving thinking on agricultural water productivity. https://doi.org/10.5337/2017.202

IPCC, 2019. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.

Keller, A.A., Keller, J., 1995. Effective Efficiency: A Water Use Efficiency Concept for Allocating Freshwater Resources.

Molden, D., 2007. Summary A Comprehensive Assessment of Water Management in Agriculture. Earthscan.

Molden, D., Sakthivadivel, R., Habib, Z., 2001. Basin-level use and productivity of water: examples from South Asia, Researh Report (IWMI).

Pérez-Blanco, C., Hrast-Essenfelder, A., Perry, C., 2020. Irrigation technology and water conservation : from panaceas to actual solutions Submitted.

Perry, C., 2007. Efficient irrigation; inefficient communication; flawed recommendations. Irrig. Drain. 56, 367–378. https://doi.org/10.1002/ird.323

Perry, C., Steduto, P., 2017. Does improved irrigation technology save water? A review of the evidence. FAO. https://doi.org/10.13140/RG.2.2.35540.81280

Perry, C., Steduto, P., Allen, R.G., Burt, C.M., 2009. Increasing productivity in irrigated agriculture: Agronomic constraints and hydrological realities. Agric. Water Manag. 96, 1517–1524. https://doi.org/10.1016/j.agwat.2009.05.005

Turral, H., Burke, J., Faures, J.-M., 2011. Climate change, water and food security. FAO Water Reports 36, FAO Water Reports 36.

Ward, F.A., Pulido-Velazquez, M., 2008. Water conservation in irrigation can increase water use. Proc. Natl. Acad. Sci. U. S. A. 105, 18215–18220. https://doi.org/10.1073/pnas.0805554105

Annex 1 – Inventory Reference List

Title	Author(s)	Year	Reference type	Journal (if applicable)	Additional cited references
Effect and Side-effect Assessment of Different Agricultural Water Saving Measures in an Integrated Framework	Raeisi et al	2019	Scientific journal paper	Agricultural Water Mngmt	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 Mngmt	
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	Int. 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 Mngmt	Zhou et al. (1996), Zhao et al. (1996), Hu (1992), Wang and Xu (1991), Wang et al (2001), Fan and Wang (2010), Zhu and 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 (2004), 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 Mngmt	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 (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 and Yang (2004), Dang et al (2006), Yi et al (2008), Shan et al (2006)
Effects of winter wheat row spacing on evaporanspiration, grain yield, and water use efficiency	Chen et al	2010	Scientific journal paper	Agricultural Water Mngmt	
Towards groundwater neutral cropping systems in the Alluvial Fans of the North China Plain	van Oort et al	2016	Scientific journal paper	Agricultural Water Mngmt	
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 Env Management	
Halting the groundwater decline in North-West India - Which crop technologies will be winners	Humpreys et al	2010	Book chapter		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 and 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 Technologis 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	USCID Conference Paper	Burt et al (2002), Ward and Pulido-Velazquez (2008)
Furrow Irrigation Management with limited water	Schneekloth et al	2006	Scientific journal paper	ASABE Conference Paper	

Water saving technologies: myths and realities revealed in Pakistan rice-wheat systems	Ahmad et al	2007	Technical report	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 Mngmt	
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 and 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		

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 and 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	CIMMYT	Alsam et al (1989)
Adoption of Drip Irrigation in Cotton: the Case of Kibbutz Cotton-growers in Israel	Feinerman and Yaron	1990	Article	Oxford Agrarian Studies	
Hydro-economic modeling of water scarcity under global change: an application to the Gállego river basin (Spain)	Graveline et al	2014	Scientific journal paper	Reg Environ Change	
Strategies for reducing subsurface drainage in irrigated agriculture through improved irrigation	Hanson and Ayars	2002	Scientific journal paper	Irrigation and Drainage Systems	Goldhamer and Peterson (1984), Fulton et al (1991), Fulton et al (1991), 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 and 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 Mngmt	
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 Mngmt	
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 and 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 and 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	Agricultural Water Mngmt	

More crop per drop': how to make it acceptable for farmers?	Luquet et al	2005	Scientific journal paper	Agricultural Water Mngmt	
Adoption and impact of zero tillage in the rice-wheat production system of Haryana	Meena et al	2016	Scientific journal paper	Indian J. Agric. Res	
Effects of Conservation Agriculture on Land and Water Productivity in Yellow River Basin, China	Nangia et al	2010	Scientific journal paper	Int J Agric & Biol Eng	
Feasibility of deficit irrigation with center-pivot to cope with limited water supplies in Alentejo, Portugal	Rodrigues et al	2003	Book chapter		
Water savings through improved irrigation techniques: basin-scale quantification in semi-arid environments	Törnqvist and Jarsjö	2012	Scientific journal paper	Water Resoure Mngmt	
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	