Food and Agriculture Organization of the United Nations

REWAS

REal WAter Savings tool

FutureWater

REWAS
REal WAter
Savings tool

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Bangkok, 2025

Required citation:
Kaune, A., Droogers, P., van Opstal, J., Steduto, P., & Perry, C. 2025. *REWAS - REal Water Savings tool.* FAO, Bangkok. https://doi.org/10.4060/cd2914en

ISBN 978-92-5-139240-9

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Executive summary

Water shortages across the Asia and the Pacific region have severe consequences for food security, as 90 percent of freshwater withdrawals in food producing regions goes towards irrigated agriculture. This significant use of and reliance on freshwater resources means that a lack of sufficient, reliable (seasonal) freshwater for the irrigation sector has direct impacts on farmer productivity, livelihoods and incomes, particularly in regions with large areas of irrigated fields. Historically, solutions for saving water in agriculture have focused specifically on improving irrigation techniques (for instance, using drip irrigation, sprinklers and pressurized systems) to save water for other purposes, such as domestic use and environmental preservation. However, a growing body of evidence shows that, when viewed at a larger scale, these apparent water "savings" resulting from reduced water withdrawals actually translate into increased water consumption. The concept of "real water savings", which broadens the perspective of water savings from the field scale to the entire river-basin scale, identifies the quantities of water that are available for alternative use outside of the agricultural sector.

Although many basin-scale hydrological models exist, there is a clear need for a more straightforward and accessible analysis tool that converts field-scale results into basin-scale impacts on real water savings. The REal WAter Savings (REWAS) tool was developed as a simple, pragmatic tool to effectively evaluate the impact of field-scale, crop-watering interventions at larger scales. Based on proven concepts of water accounting and water productivity, and using appropriate water terminology (as promoted by FAO), the REWAS approach is to "Follow the Water"; that is, to consider the reuse by downstream users of drainage, runoff and percolation to the groundwater, instead of labeling it a "loss".

This publication examines the underlying concepts of the REWAS tool and provides examples of how users have successfully applied it in two different contexts. The document also serves as a guide for users wishing to undertake a quick impact assessment of detailed field-scale experiments (using models or pilot plots) on potential basin-scale water savings. By following the concepts and guidelines in this document, stakeholders and decision-makers can improve how they manage their agricultural water systems at a larger scale and achieve real water savings.

1. Introduction

Irrigated agriculture is the largest consumer of freshwater withdrawals in Asia, responsible for up to 90 percent of water consumption in many of Asia's food-producing regions. Unsurprisingly, water shortages are most prevalent in regions with large areas of irrigation, often to the extent that the irrigation sector is heavily affected by a lack of sufficient, reliable (seasonal) freshwater, with direct impacts on farmer productivity, livelihoods and incomes. As such, options to save water tend to focus specifically on irrigation. Improved irrigation techniques (such as drip irrigation, sprinkler irrigation and pressurized systems) are promoted as legitimate means of saving water for other uses (including domestic use and the environment). However, a growing body of evidence shows that, in the vast majority of cases, apparent water savings at field scale translate into increased water consumption when assessed at larger scales. Yet despite this growing and irrefutable body of evidence, "water saving" technologies continue to be promoted, subsidized and implemented as a solution to water scarcity in agriculture, without careful evaluation of wider impacts. A summary of the evidence can be found in the accompanying FAO (2021) report *Crop water productivity options to achieve real water savings*.

There is therefore an urgent need to develop and use simple, pragmatic tools that can evaluate the impact of field-scale, crop-water interventions at larger scales. More specifically, results from widely used field-scale models such as CropWat and AquaCrop should be assessed on their basin-scale water savings. Although many basin-scale hydrological models exist, there is a clear need for a more straightforward analysis tool that converts field-scale results into first-order, basin-scale impacts on real water savings.

The REWAS (REal WAter Savings) tool was developed for undertaking quick impact assessments of detailed field-scale experiments (using either models or pilot plots) on basin-scale potential water savings. REWAS is based on proven concepts of water accounting and water productivity, as well as appropriate water terminology, as promoted by FAO in *Crop water productivity options to achieve real water savings* (FAO, 2021). This document provides the underlying concepts of REWAS and provides guidance for its application as well as examples of its application in two contexts.

In addition to this document, a training manual is available which explains in detail the concepts of real water savings and the use of the REWAS tool. The manual includes clear examples as well as questions and answers about the tool. For further discussion and a summary of real water savings, see the accompanying report, *Crop water productivity options to achieve real water savings* (FAO, 2021).

Chapter 2 of this document presents an overview of the REWAS tool. Details about the required input data and the REWAS interface and underlying equations are presented in Chapter 3. Chapter 4 provides more detailed information about the underlying theory and concepts of REWAS. Finally, Chapter 5 presents examples of REWAS applications in two Asian countries.

2. Overview of REWAS

2.1 Concept of REWAS

REWAS is a user-friendly tool designed to assess real water savings for field interventions in irrigation systems that looks beyond the traditional concept of water savings at the field scale. While traditional field-level water-savings measurement approaches often consider drainage, runoff and percolation to be "losses", REWAS "follows the water"; that is, it takes into account the fact that water from drainage, runoff and percolation is used by downstream users, thus providing a more accurate account of actual water savings.

In REWAS, real water savings are determined for field-intervention scenarios by obtaining the relative change in water consumption and the relative change in return flows. Current water consumption and return flows in a selected irrigation system are used as the reference scenario for obtaining the relative change in water flows. In addition to water consumption and return flows, storage change and water productivity are obtained for each field intervention and for the reference scenario. As shown in Table 1, REWAS measures the flows at field scale in water depth (mm/season), and the flows at irrigation-system scale (consisting of irrigated fields) in water volume (MCM/season) for a given irrigated area. Water productivity is shown in kg/m^3.

TABLE 1
Example of REWAS results: apparent water savings at field scale and real water savings at irrigation-system scale

RESULTS				
		Scenario		
		Reference	Intervention A	Intervention B
RESULTS FIELD	Units			
Consumption, beneficial BC	(mm)	403	242	242
Consumption, non-beneficial NBC	(mm)	163	130	130
Return flows	(mm)	555	21	21
Storage change CS	(mm)	0.0	0.0	0.0
Water productivity WP	(kg/m^3)	0.93	1.03	1.03
Apparent water savings FWS	(mm)	-	567	567
Percentage of Apparent Water Savings %FWS	**%**	**-**	**51%**	**51%**
RESULTS SYSTEM				
Consumption, beneficial BC	(MCM)	40.3	24.2	36.3
Consumption, non-beneficial NBC	(MCM)	16.3	13.0	19.5
Return flows, recoverable RF	(MCM)	47.6	1.8	2.7
Return flowsnon-recoverable NRF	(MCM)	7.9	0.3	0.5
Storage change CS	(MCM)	0.0	0.0	0.0
Water productivity WP	(kg/m^3)	0.93	1.03	1.03
Real water savings RWS	(MCM)	-	10.9	4.2
Percentage of Real Water Savings %RWS	**%**	**-**	**10%**	**4%**

Source: Authors' own elaboration.

In REWAS, a field intervention is assumed to be uniform over the entire area of the irrigation system without spatial differences in crop development, crop transpiration, soil characteristics or field management. Many other tools (such as SPHY, Wflow and VIC) are able to assess spatial variability, but the unique feature of REWAS is that the tool follows the water and provides the user with clear reasoning on how much water is really saved in an irrigation system with different field interventions. Examples of field interventions are: i) changing the irrigation application, ii) changing to another irrigation technology, iii) changing to mulching practices, and iv) changing the plant density (among other practices and combinations). Any of these interventions will lead to a change in water consumption, return flows, storage and water productivity. More examples of field interventions and corresponding changes in flows and productivity can be found in the document Guidance: Crop water productivity options to achieve real water savings (FAO, 2015).

For each field intervention, REWAS determines the impact in water consumption, return flows, storage change and water productivity at field scale and at irrigation-system scale. REWAS follows the water flows and determines the apparent water savings at field scale and the real water savings at irrigation-system scale. At field scale, REWAS assumes the farmers believe that drainage and percolation are water losses that cannot be recovered. At irrigation-system scale, part of the drainage and part of the percolation are recoverable flows downstream. REWAS allows the user to choose a recoverable flow fraction of drainage and a recoverable flow fraction of percolation. Hence, recoverable flows and non-recoverable flows from drainage and percolation are obtained, which is key to determining the real water savings.

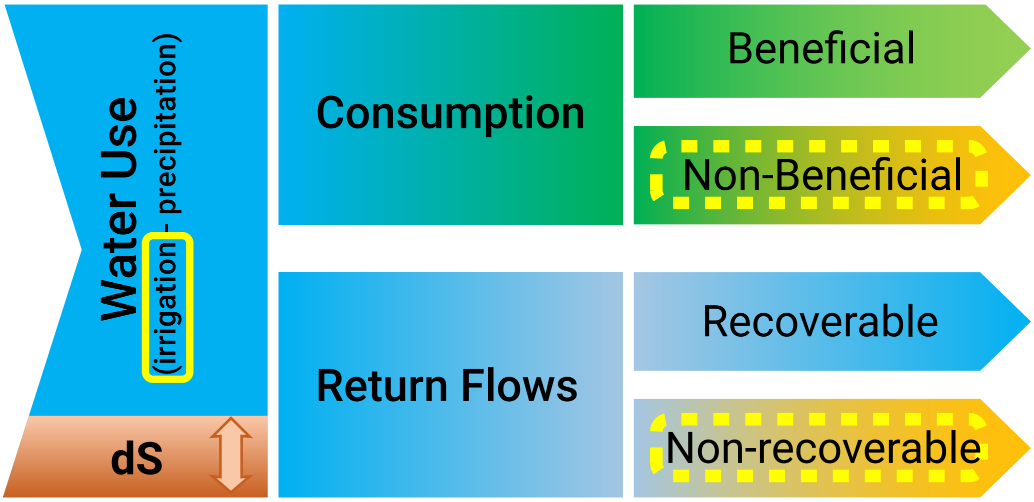
REWAS is developed in Microsoft Excel to enhance usability, reach, transparency and transferability of data input and output. Input data is obtained from studies, field trials, measurements, ground observations or remote sensing. REWAS results are based on proven concepts of water accounting and the appropriate water terminology, as promoted by FAO (FAO, 2013).

2.2 Traditional vs REWAS approaches to water-savings calculation

The main objective of REWAS is to assess quickly the impact of field-scale crop-water interventions on basin-scale water savings, taking into consideration the downstream use of drainage, runoff and percolation. To briefly introduce the real-water-savings results provided by REWAS, a typical water-savings case is summarized here.

A study from Nepal (Jha *et al*., 2016) reported that, by reducing irrigation applications, 75 percent water savings were achieved. However, the study failed to use the "Follow the Water" principle, assuming that at all return flows were losses, while in reality 80 percent of those return flows are recovered by downstream users. Figure 1 shows the "Follow the Water" approach of the REWAS tool, vs the approach used in the study. While the study reported water savings in irrigation only (as shown by the solid yellow box in Figure 1), REWAS focuses on the recoverable return flows and non-beneficial consumption (shown by the dotted yellow boxes), where real water savings can be achieved.

FIGURE 1
Follow the Water approach in the REWAS tool



Source: Adapted from Van Opstal, J., Droogers, P., Kaune, A., Steduto, P., & Perry, C. 2021. Guidance on realizing real water savings with crop water productivity interventions. FAO Water Reports 46. (also available at https://doi.org/10.4060/cb3844en); Perry, C. 2011. Accounting for water use: terminology and implications for saving water and increasing production. Agr. Water Manag. 98, 1840–1846. https://doi.org/10.1016/j.agwat.2010.10.002.

The results obtained using the REWAS tool (Table 2) clearly show that the claimed water savings of 75 percent are inaccurate from a basin perspective and that the real water savings at basin scale are much smaller – in the order of 6 percent.

TABLE 2
REWAS tool analysis of real water savings for the Nepal case

INPUT DATA			
		Scenario	
		Reference	Intervention A
FIELD	Units		
Rainfall	(mm)	910	910
Irrigation	(mm)	217	54
Crop transpiration	(mm)	720	720
Soil evaporation	(mm)	43	0
Drainage	(mm)	182	122
Percolation	(mm)	182	122

RECOVERABLE FLOW FRACTION			
Recoverable drainage fraction RD	(%)	80%	80%
Recoverable percolation fraction RP	(%)	80%	80%

RESULTS			
		Scenario	
		Reference	Intervention A
Percentage of real water savings	%	-	**6%**

Source: Authors' own elaboration.

3. REWAS interface, output and input

3.1. REWAS interface

The REWAS interface was developed in Microsoft Excel for easy usability, reach, transparency and transferability of data input and output. Table 3 shows the input data interface. Users can manually insert data values in the assigned cells for the reference scenario and for intervention A and intervention B. Columns are also available for interventions C, D and E, which the user can “unhide” as needed. With the data provided, REWAS can assess the impacts of different field interventions. This could include, for example, different irrigation applications or technologies, different agronomic practices, or different irrigated areas. Each field intervention may result in differences in irrigation, crop transpiration, soil evaporation, drainage and percolation. These changes can be determined from field trials or through remote sensing. Or, instead of using data from field trials or remote sensing, the user can import AquaCrop results by clicking on the yellow or green arrow for each scenario. (Steps on how to import AquaCrop results are described in Section 3.4.) Also, the area of the irrigation system and the recoverable flow fraction for drainage and percolation can be filled in manually. Chapter 4 provides more information about the recoverable flow fraction.

TABLE 3

REWAS Input data: field data, irrigation area and recoverable flow fractions

If needed, click to import AquaCrop Results		Ref	A	B
INPUT DATA				
		Scenario		
		Reference	Intervention A	Intervention B
FIELD	Units			
Rainfall	(mm)			
Irrigation	(mm)			
Crop transpiration	(mm)			
Soil evaporation	(mm)			
Drainage	(mm)			
Percolation	(mm)			
Yield	(kg/ha)			
SYSTEM				
Area	(ha)			
RECOVERABLE FLOW FRACTION				
Recoverable drainage fraction RD	(%)			
Recoverable percolation fraction RP	(%)			

Source: Authors' own elaboration.

3.2. Required input data

REWAS input data comprises rainfall, irrigation, crop transpiration, soil evaporation, drainage and percolation in water depth per cropping season (mm/season) in an irrigated field (Table 4). The harvested crop yield (kg/ha) for the selected cropping season can also be provided to obtain the water productivity. (Details about water productivity are presented in Chapter 4). The input data can be obtained from field trials, remote sensing, crop growth models or any other source of information available. If necessary, REWAS has the option to import data from FAO AquaCrop simulations. (Box 1 elaborates further on obtaining data in real-world situations.) REWAS users choose a desired irrigated area (in hectares) to obtain the flow results in millions of cubic meters (MCM) and the crop production in millions of kilograms (Mkg). In addition, REWAS users choose a recoverable flow fraction of drainage and a recoverable flow fraction of percolation. Box 2 (and Section 4.3) elaborates further on recoverable flow fractions from return flows.

TABLE 4
Input variables used to understand water savings

Input variables	Units	Normal range of values
Rainfall	mm/season	0–1000
Irrigation	mm/season	0–1000
Crop transpiration	mm/season	0–1000
Soil evaporation	mm/season	0–1000
Drainage	mm/season	0–1000
Percolation	mm/season	0–1000
Yield	kg/ha	0–1000

Source: Authors' own elaboration.

BOX 1

Obtaining data in real world situations

The main reason for using AquaCrop is to be able to input estimate values for actual crop transpiration and soil evaporation for real field conditions. This still relies on a fair number of assumptions. Actual crop transpiration and soil evaporation should be obtained with the easiest method available. If remote sensing data is available, it would be a good alternative.

Generally, drainage (sub-surface and/or surface flows) and percolation (flow to aquifer) is only derived at field experiment stations and is difficult to assess on farm. Real values will always require some sort of measurement set up (e.g. soil moisture device to assess fluxes below the root zone) which is cumbersome. In theory, measuring surface drainage is easier (e.g. using calibrated Parshall flumes), but often hard to do in practice. AquaCrop can provide a guidance on how drainage and percolation flows change for different soil conditions and field interventions.

Box 2

Recoverable flow fractions from return flows

Recoverable flow fractions from return flows are key to estimate real water savings. Using the recoverable flow fraction from drainage allows the estimate of the water returning to a river for potential reuse. In addition, using the recoverable flow fraction from percolation allows the estimate of water returning to an aquifer for potential reuse. Values of recoverable flow fractions can vary between 20 percent and 90 percent depending on the basin. Accurate values of recoverable flow fractions are difficult to get. However, knowledge about non-recoverable flows in specific basins can provide an estimate of the recoverable flow fraction. Non-recoverable return flows are flows to the sea, flows to saline aquifers or flows to other economically unviable sinks. BOX 4 elaborates further on non-recoverable return flows in Asia.

3.3. Obtaining results in REWAS

The output results of the REWAS tool are separated at field (FIELD) and system (SYSTEM) scale (Table 5). Output variables are given in mm at field scale and MCM at system scale, according to the area of the irrigation system (defined in the input variables). The output results are provided using the terminology of the water accounting framework developed by Perry (2007). (See Section 4.1 and Section 4.2 for more information about water accounting.) The water productivity results are also provided. The water savings for each scenario shown in the results can be used to assess the difference between the reference scenario and different field interventions. The real water savings are determined at system scale.

TABLE 5

REWAS output results at field scale (units in mm) and at system scale (units in MCM), to evaluate real water savings for different intervention scenarios

RESULTS				
		Scenario		
		Reference	Intervention A	Intervention B
RESULTS FIELD	Units			
Consumption, beneficial BC	(mm)			
Consumption, non-beneficial NBC	(mm)			
Return flows	(mm)			
Storage change CS	(mm)			
Water productivity WP	(kg/m^2)			
Apparent water savings FWS	(mm)			
Percentage of apparent water savings %FWS	**%**			
RESULTS SYSTEM				
Consumption, beneficial BC	(MCM)			
Consumption, non-beneficial NBC	(MCM)			
Return flows, recoverable RF	(MCM)			
Return flowsnon-recoverable NRF	(MCM)			
Storage change CS	(MCM)			
Water productivity WP	(kg/m^2)			
Real water savings RWS	(MCM)			
Percentage of real water savings %RWS	**%**			

Source: Authors' own elaboration.

Table 6 shows the interface of intermediate results in REWAS. Inflows and outflows at field and system scale are determined. At system scale the intermediate results for drainage and percolation volumes for recoverable flow fractions are obtained. (The calculations developed in this table are described in Chapter 4).

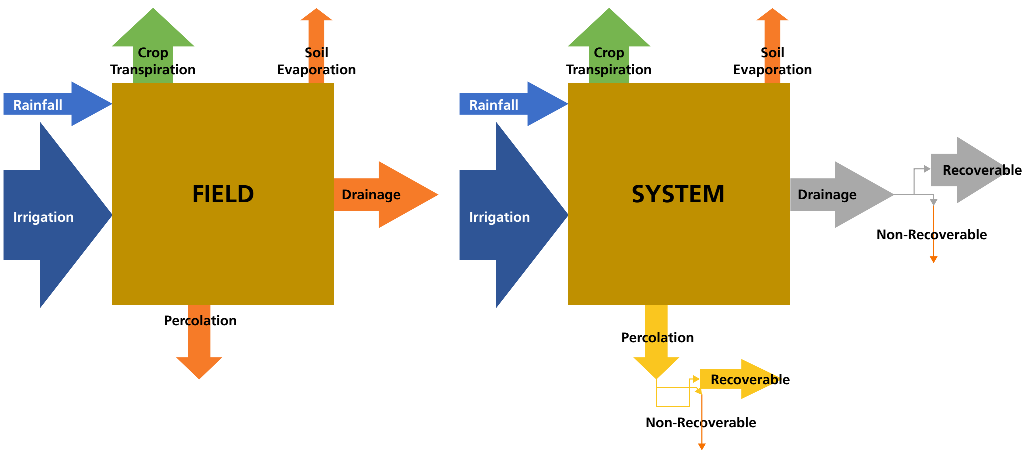
TABLE 6
Intermediate results in REWAS showing inflows and outflows at field and system scale

INTERMEDIATE RESULTS				
		Scenario		
		Reference	Intervention A	Intervention B
FIELD	Units			
Inflow, total	(mm)			
Outflow, total	(mm)			
SYSTEM				
Rainfall	(MCM)			
Irrigation	(MCM)			
Crop transpiration	(MCM)			
Soil evaporation	(MCM)			
Drainage	(MCM)			
Percolation	(MCM)			
Production	(Mkg)			
Drainage, total	(MCM)			
Drainage, recoverable	(MCM)			
Drainage, non-recoverable	(MCM)			
Percolation, total	(MCM)			
Percolation, recoverable	(MCM)			
Percolation, non-recoverable	(MCM)			
Inflow, total	(MCM)			
Outflow, total	(MCM)			

Source: Authors' own elaboration.

The user can select which scenario to show in the water balance plot (inflows and outflows) at field scale and system scale (Figure 2). The size of the arrows changes according to the selected scenario. At system scale, recoverable flows and non-recoverable flows for drainage and percolation are obtained.

FIGURE 2
REWAS water balance plot with inflows and outflows at field scale and system scale



Source: Authors' own elaboration.

3.4. Importing data from AquaCrop

REWAS input data can be obtained from various sources, such as field experiments on pilot plots, published data, model outputs and remote sensing. Since AquaCrop is considered the standard to undertake crop-water-intervention analysis, REWAS has an option to import AquaCrop results directly. This section describes the steps for importing AquaCrop results, using an example from Namobuddha, Nepal as the reference scenario. AquaCrop results are prepared in advance in the "AC" folder, so the user can select these results as input data in REWAS.

The steps for importing AquaCrop results in REWAS are:

1. Open the REWAS Excel file: REWAS_v6.xlsm.
2. Click on: "Main".
3. Look for "If needed, click to import AquaCrop Results" and click on the desired scenario: Ref, A or B (Table 7). (For this example, the user would first click on the reference scenario: Ref.).
4. Browse to the directory where one of the AquaCrop Output files (*.out) is located.
5. Browse to the "AC" folder containing folders for different countries. (For this example, the user would select the "Nepal" folder [Figure 3], where the user would find different field interventions [e.g. change in irrigation application, change in plant density, change in soil fertility, etc.] for rice in Namobuddha, Nepal.)
6. Input the desired intervention by clicking on it and then clicking "Open" to import the file. Repeat the procedure for other desired field interventions. (In this example, reference scenarios are imported into REWAS for the field intervention "Irrigation [see Figure 4, Figure 5 and Table 8]).
7. Click and open the file "ProjectPROseason.OUT" (Figure 5). This will automatically import the required data into the corresponding column in REWAS (Table 8). (If no file is selected a message will appear: "No file was selected". If this occurs, press "Ok" and try again).

TABLE 7
REWAS input data interface with option to import field-intervention data from AquaCrop

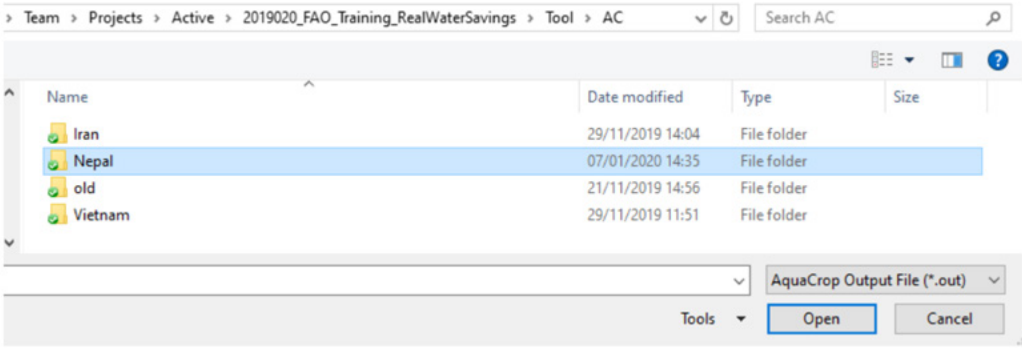
If needed, click to import AquaCrop Results | Ref | A | B

INPUT DATA				
		Scenario		
		Reference	Intervention A	Intervention B
FIELD	Units			
Rainfall	(mm)			
Irrigation	(mm)			
Crop transpiration	(mm)			
Soil evaporation	(mm)			
Drainage	(mm)			
Percolation	(mm)			
Yield	(kg/ha)			

Source: Authors' own elaboration.

FIGURE 3

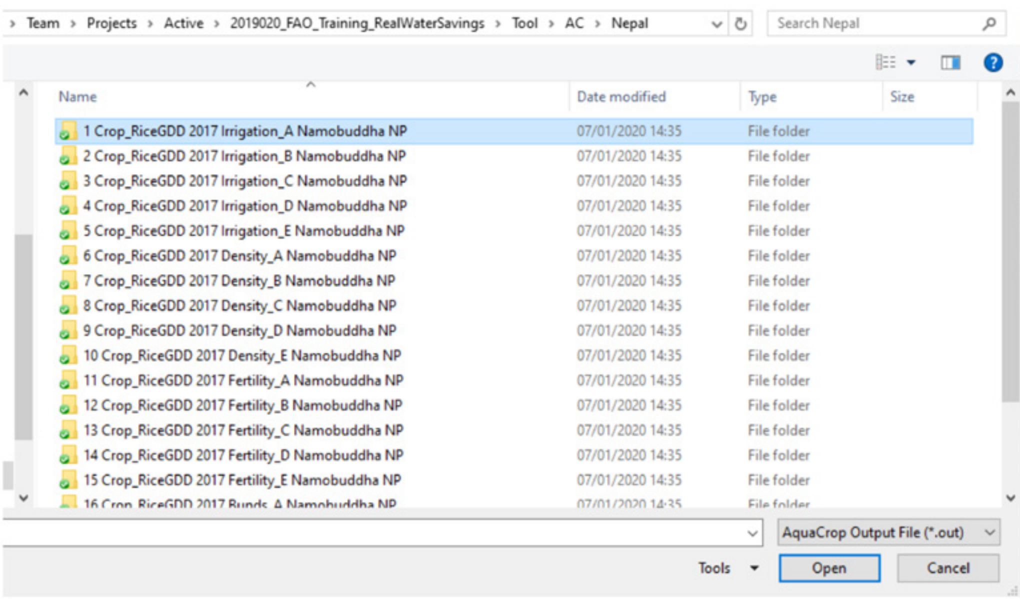
Importing field intervention data from AquaCrop in REWAS: Click on the desired country to access field interventions in the country



Source: Food and Agriculture Organization of the United Nations and FutureWater. 2020. REWAS. [Accessed on 29 March 2020]. https://www.fao.org/faostat/en/#data/QC. Licence: CC-BY-4.0.

FIGURE 4

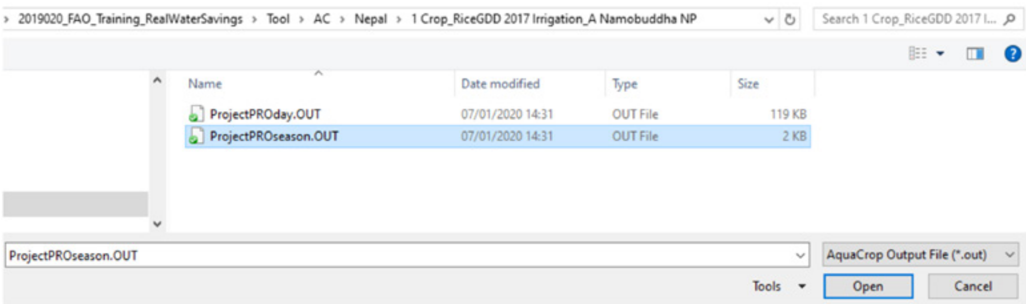
Importing field intervention data from AquaCrop in REWAS: Click on the desired intervention to access data



Source: Food and Agriculture Organization of the United Nations and FutureWater. 2020. REWAS. [Accessed on 29 March 2020]. https://www.fao.org/faostat/en/#data/QC. Licence: CC-BY-4.0.

FIGURE 5

Importing field intervention data from AquaCrop in REWAS: Click on the desired intervention to import data



Source: Food and Agriculture Organization of the United Nations and FutureWater. 2020. REWAS. [Accessed on 29 March 2020]. https://www.fao.org/faostat/en/#data/QC. Licence: CC-BY-4.0.

TABLE 8
REWAS input data interface showing imported AquaCrop result for reference scenario "1 Crop_ RiceGDD 2017 Irrigation_A Namobuddha NP" for irrigated rice in Nepal

If needed, click to import AquaCrop Results | Ref | A | B

INPUT DATA				
		Scenario		
		Reference	Intervention A	Intervention B
FIELD	Units			
Rainfall	(mm)	707		
Irrigation	(mm)	270		
Crop transpiration	(mm)	216		
Soil evaporation	(mm)	176		
Drainage	(mm)	353		
Percolation	(mm)	248		
Yield	(kg/ha)	3.12		

Source: Authors' own elaboration.

In AquaCrop the crop yield is given in t/ha units. Hence, the user must change the crop yield to kg/ha by multiplying by a factor of 1000. In this case 3.12 t/ha must be changed to 3 120 kg/ha to obtain the correct REWAS results.

4. Theory and concepts underlying the REWAS tool

4.1 Water accounting

For water accounting it is important to distinguish between "using" water (for example, to generate hydropower or to wash clothes) and "consuming" water (for example, through evapotranspiration [ET] in an irrigation system). In the former case, the vast majority of the water used returns directly to the same hydrological system from which it was abstracted, perhaps at a different location, perhaps polluted in some way, but physically the water remains available for reuse. When water is consumed through evaporation and transpiration, however, it is no longer available (except in closed systems, such as hydroponic greenhouses, where it may be condensed and reused).

Another important clarification in water accounting relates to the engineering perspective, which is entirely valid and appropriate for planning, designing and operating irrigation facilities. This perspective tends to consider water that flows beyond the boundary of the irrigation scheme as losses. An environmental analyst, on the other hand, might be very interested in these "losses" as a source of recharge to aquifers or flows into wetlands. That is, the engineer's "loss" is the environmentalist's "source".

The water accounting framework proposed by Perry (2007) differentiates the various flows that are associated with any type of water use and can be applied to any sector, at any scale, without modification. Water use is defined as any application of water to a selected purpose (irrigation, diversion through a power station, domestic washing, industrial processes, etc.). All water use falls into one or more of the following categories.

1. Consumptive use (conversion of water into water vapour), comprising:
    a. Beneficial Consumption (BC)
        - Crop transpiration
        - Evaporation from cooling towers
    b. Non-beneficial consumption (NBC)
        - Evaporation from free water surfaces and from wet soil
        - Transpiration by weeds
2. Non-consumptive use (also called return flows), comprising:
    a. Recoverable flows (RF)
        - Returning to a river for potential reuse
        - Returning to an aquifer for potential reuse
    b. Non-recoverable flows (NRF)
        - Flowing to the sea
        - Other economically unviable sink
3. Change in storage (CS)

The water accounting framework is based on the law of conservation of mass, resulting in the following equation (Equation 1) for water-use calculation:

$$(1)\ \textit{Water use} = BC + NBC + RF + NRF + CS$$

4.2. Water accounting in REWAS

REWAS is based on the water accounting framework put forth by Perry (2007). In REWAS, the water accounting framework is simplified in order to evaluate water use in irrigation systems. Consumptive use is limited to crop transpiration and soil evaporation, and non-consumptive use is limited to recoverable and non-recoverable flows from drainage and percolation in irrigation systems (Table 9). Additional analysis considering other water users (such as the environment and urban areas) is conducted using the WEAP tool. More information about the application of WEAP can be found in the training manual developed by FutureWater and FAO, Crop water productivity options to achieve real water savings (FAO, forthcoming).

TABLE 9
Water accounting framework applied in the REWAS tool for evaluation of water use in irrigation systems

<table>
<tr><td rowspan="5">Water use in irrigation systems (WU)</td><td rowspan="2">Consumptive use (CU)</td><td>Beneficial consumption (BC)
• Crop transpiration</td></tr>
<tr><td>Non-beneficial consumption (NBC)
• Soil evaporation</td></tr>
<tr><td rowspan="2">Non-consumptive use or return flows (NCU)</td><td>Recoverable flows (RF)
• From drainage
• From percolation</td></tr>
<tr><td>Non-recoverable flows (NRF)
• From drainage
• From percolation</td></tr>
<tr><td colspan="2">Change in storage (CS)</td></tr>
</table>

Source: Authors' own elaboration.

In REWAS, it is important to determine the different components of the water use to evaluate the real impact at the level of irrigation systems. For example, if a farmer increases the crop area in irrigation system A by introducing improved irrigation technology and the volume of water delivered to his farm is unchanged, some or all of the following changes occur:

- beneficial consumption (crop transpiration) increases;
- non-beneficial consumption (evaporation from wet soil) decreases;
- percolation decreases;
- drainage flows decrease.

The increase in beneficial consumption is usually the most important impact. Indeed this is a primary reason for introducing improved irrigation technology. This typically means that the overall result is increased water consumption in irrigation system A and reduced return flows to aquifers and to the surface system. Describing these changes in flows is essential to promote clarity in the reporting and evaluation of the physical impact of improved irrigation technology. Hence, when proponents of drip irrigation argue that the technique can “double the irrigated area”, this should be interpreted as “doubling the proportion of water delivered to the farm that is consumed”, thus dramatically decreasing return flows.

4.3. Recoverable flows for real water savings

The extent to which return flows to percolation and drainage are valuable to other users is key to determine real water savings in irrigation systems. Recoverable flows vary depending on environmental, infrastructure and management aspects of irrigation systems. For example, if the irrigation system has relatively light soils and water is pumped from underlaying aquifers to irrigate the fields, the recoverable water from percolation may be high.

In REWAS, recoverable flow fractions are used for drainage and percolation. Typical recoverable flow fractions are between 20 percent and 90 percent. As explained, these values vary depending on the type of irrigation system. Researchers and field practitioners can contribute to effective water accounting by better estimating, recommending and classifying recoverable flow fractions for different types of irrigation systems.

The intention of REWAS is to allow scenario analysis using established recoverable flow fractions to obtain recoverable flows from drainage and percolation, and thus to determine real water savings in irrigation systems. In REWAS, the recoverable flows from drainage and percolation are obtained as follows (Equation 2 and Equation 3):

$$DrainageRecoverable = DrainageTotal \times RD \quad (2)$$

$$PercolationRecoverable = PercolationTotal \times RP \quad (3)$$

In Equation 2 and Equation 3, RD is the recoverable drainage fraction, DrainageTotal is the drainage flow, and *DrainageRecoverable* is the recoverable flow from drainage. *RP* is the recoverable percolation fraction, *PercolationTotal* is the percolation flow, and *PercolationRecoverable* is the recoverable flow from percolation.

In REWAS, the total recoverable flow in irrigation systems (RF_{Sys}) is obtained using recoverable flows from both percolation and drainage (Equation 4):

$$RFSys = DrainageRecoverable + PercolationRecoverable \quad (4)$$

Corresponding non-recoverable flows from drainage ($DrainageNRF_{Sys}$) and non-recoverable flows from percolation ($PercolationNRF_{Sys}$) are obtained with Equation 5 and Equation 6. In Equation 7, the total non-recoverable flow (NRF_{Sys}) is obtained:

$$DrainageNRF_{Sys} = (DrainageTotal) \times (1\text{-}RD) \quad (5)$$

$$PercolationNRF_{Sys} = (PercolationTotal) \times (1\text{-}RP) \quad (6)$$

$$NRF_{Sys} = DrainageNRF_{Sys} + PercolationNRF_{Sys} \quad (7)$$

4.4. Water productivity

Water productivity, at a high-level, can be defined as the net return for a unit of water used (Molden *et al.*, 2010). Improvement of water productivity aims to produce more food, income, better livelihoods and ecosystem services with the same water or less. Water productivity consists of two components: crop production and water consumption. The water productivity of a crop is defined as the ratio between the amount of crop produced and the amount of water consumed to obtain the production. In REWAS, water productivity is calculated with the following equation (Equation 8):

$$(8)\ WP = \frac{Pr}{(BC+NBC)}$$

In Equation 8, *Pr* is the crop production (Mkg) obtained with the crop yield and the area of the irrigation system; the beneficial consumption, *BC*, is the crop transpiration (Mm^3); and the non-beneficial consumption, *NBC*, is the soil evaporation (Mm^3).

For common field crops (such as food grains, forage crops, fibres and sugar) the relationship between crop yield and water consumption is essentially linear (Fereres and Soriano, 2007; Howell, 1990; Steduto, Hsiao, *et al.*, 2012) over a wide range of intermediate yield levels. This linear relationship is not strictly proportional. The relationship between yield and ET intersects the consumption axis at a positive value.

An agronomic practice that has shown some influence on water productivity is deficit irrigation. In practice, deficit irrigation consists of applying water below the crop-water requirements for evapotranspiration (ETc) (Fereres and Soriano, 2007). As a result, two situations may develop. In one case, stored soil water and/or rainfall supply the deficit, and the crop does not experience ET deficits. In this case, there are no savings in total water consumption. This scenario is often desirable in terms of making the best use of stored soil water, but it requires precise management and water accounting to ensure that ET deficits do not develop. The second situation occurs when the irrigation supply is deliberately kept low enough to create deficits and actual crop ET is less than ETc. In this second case, given the close association between production and transpiration, crop yields are generally lower than those obtained under full irrigation.

Some crops (trees and vines are the most common examples) react positively to ET deficits at specific growth stages, offering opportunities for using deficit irrigation to increase water productivity. For the major cereals, however, the opportunities are extremely limited. For maize, many experiments have shown that full irrigation is the best economic option, and if water is limited it should be concentrated in a smaller area. For wheat, the evidence from supplemental irrigation research in the Near East and other areas shows that, while you can achieve higher irrigation-water productivity, there is almost always some yield penalty. An optimal level of deficit may be found if water is very expensive or scarce, but it would be at around 80 to 90 percent of ETc. Cotton and grain sorghum (among other field crops) are also good candidates for deficit irrigation. For most field and vegetable crops, deficit irrigation has limited prospects and needs to be assessed through an optimization exercise based on local data. Even then, from a practical standpoint, managing small reductions in ET is very difficult, risky, and tends to lead to soil salinization. In the case of woody perennials (fruit trees and vines), deficit irrigation is a viable option to save water and optimize the use of limited water resources (Steduto, Hsiao, *et al.*, 2012).

Another agronomic practice that has been shown to influence water productivity is supplemental irrigation. While supplemental irrigation can be interpreted differently based on the environments it is implemented in, it is generally considered a form of deficit irrigation in which small amounts of water are applied to supplement rainfall. Supplemental irrigation was developed primarily in the arid areas of the Near East as a means to improve winter cereal production (although the practice has also been used in humid areas). Supplemental irrigation is often promoted in conjunction with rainwater harvesting (Oweis and Hachum, 2006). Many experiments have shown that relatively small amounts of water applied to winter cereals around flowering have dramatic effects on yield and on water productivity (kg/m^3). The explanation is that the maintenance of adequate water status during that time has a positive effect on maintaining the crop harvest index under the drought conditions of those water-limited environments. However, despite the positive results at the experimental level, supplemental irrigation has not been widely adopted by farmers. The reasons for the limited adoption of supplemental irrigation have to do with the difficulties in implementing the technique. The main limitations in this regard are: a) uncertainties in the return on the investment required for the collection and application of the irrigation water; b) variations in the timing of water deficits relative to the limited irrigation supply available; and c) once a supply of water is made available, there is a tendency to concentrate it to maximize production per unit of irrigated area (often of high-value crops such as vegetables) rather than spreading it over a larger area as supplemental irrigation of cereals. For these reasons, the application of supplemental irrigation in practice is more limited than would be expected given the results of the practice in experimental settings. There are, however, a few cases in fruit-tree production (such as olive trees) where it has been practiced with success. Box 3 elaborates further on supplemental irrigation and water productivity.

In sum, for a given crop and a given climate, increases in production are associated with increases in water consumption by the crop, and for most field crops, water productivity (kg/m^3) is highest when water consumption and yield per hectare are maximum. This is because some degree of (non-beneficial) evaporation from wet soil or foliage is unavoidable but comprises a smaller proportion of total consumption when transpiration is at its maximum potential level – not least because healthy plant development quickly shades the soil and minimizes soil evaporation.

BOX 3

Supplemental irrigation and water productivity

The key attraction of supplemental irrigation is the marginal waterproductivity improvement. However, comparisons of waterproductivity outputs are complicated with most crops. Waterproductivity components are crop yield and evapotranspiration, which is sourced from rainfall and irrigation. With simple metrics we cannot separate the waterproductivity components due to rainfall and irrigation, and even in experimental conditions it is hard to determine the marginal waterproductivity improvement of added irrigation. Adoption of supplemental irrigation in Asia has been low, but it is common practice in European farming.

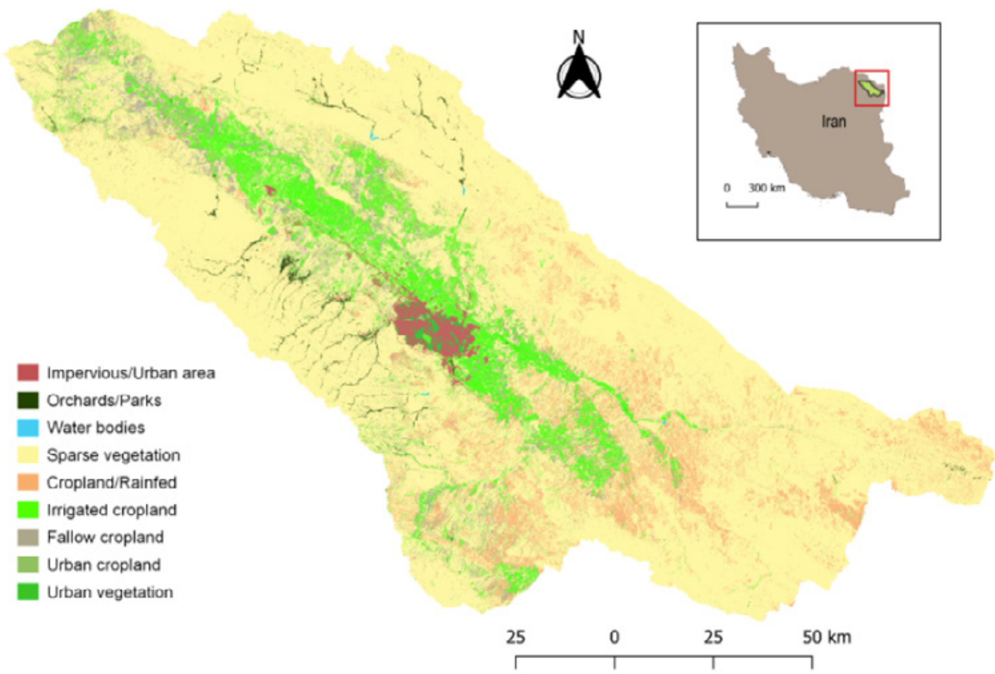
5. Examples of applications of REWAS

The following are examples of REWAS application in irrigation systems in Asia. Irrigation systems in Iran (Islamic Republic of) and Viet Nam were evaluated for real water savings and water productivity.

5.1. Irrigation system in the Mashhad basin, Iran (Islamic Republic of)

The Mashhad basin is located in the northeast of Iran (Islamic Republic of). The total irrigated area in the Mashhad basin is approximately 160 000 ha (Figure 6), 20 percent of which is pressurized irrigation (e.g. drip irrigation) and 80 percent of which is surface irrigation. Wheat and barley are the dominant crops, accounting for 46 percent and 26 percent, respectively, of the total irrigated area (Iran Statistical Center, 2015). Most of the irrigated water is pumped from aquifers serving irrigation systems ranging in size from 50 ha to 5 000 ha.

FIGURE 6
Irrigated cropland in the Mashhad basin, Iran (Islamic Republic of)



Source: Pareeth, S., Karimi, P., Shafiei, M. & De Fraiture, C. 2019. Mapping Agricultural Landuse Patterns from Time Series of Landsat 8 Using Random Forest Based Hierarchial Approach. Remote Sensing, 11(5): 601. https://doi.org/10.3390/rs11050601.

Note: Refer to the disclaimer on page ii for the names and boundaries used in this map.

FIGURE 7
Typical drip irrigation system for wheat, Mashhad basin, Iran (Islamic Republic of)

A drip irrigation system of 5 000 ha was selected for REWAS application (Figure 7). The assumption was made that only wheat is grown in the irrigation system. The growth season of wheat is between October and June, with irrigation beginning in March.

The reference scenario is the current irrigation used in the farm with a season application of 450 mm. In intervention A, the application is changed to 90 mm. In Table 10, the input data in REWAS is shown for two measured scenarios (reference and intervention A). The inflows are rainfall and irrigation, and the outflows are crop transpiration, soil evaporation, drainage and percolation. Rainfall remains constant for each scenario (171 mm). For the reference scenario (irrigation of 450 mm), crop yield is 5 320 kg/ha, crop transpiration is 382 mm, drainage is 119 mm, and percolation is 55 mm. For intervention A (irrigation with 90 mm) the crop yield is significantly reduced to 3 200 kg/ha; percolation is 11 mm and drainage is 15 mm. The decrease in irrigation application results in a reduction in outflows and a decrease in crop yield.

TABLE 10
Example of input data for REWAS in Iran (Islamic Republic of)

INPUT DATA			
		Scenario	
		Reference	Intervention A
FIELD	**Units**		
Rainfall	(mm)	171	171
Irrigation	(mm)	450	90
Crop transpiration	(mm)	382	185
Soil evaporation	(mm)	65	50
Drainage	(mm)	119	15
Percolation	(mm)	55	11
Yield	(kg/ha)	5320	3200

Source: Authors' own elaboration.

In Table 11, further input data is provided including the size of the irrigation system (5 000 ha) and recoverable flow fractions. Based on observations, a 70 percent recoverable flow fraction for drainage and for percolation is assumed.

TABLE 11
Input data: size of the irrigation system (5 000 ha) and recoverable flow fractions in Iran (Islamic Republic of)

SYSYEM			
Area	(ha)	5000	5000

RECOVERABLE FLOW FRACTION			
Recoverable drainage fraction RD	(%)	70%	70%
Recoverable percolation fraction RP	(%)	70%	70%

Source: Authors' own elaboration.

In Table 12, intermediate results for total inflows and total outflows are shown at field and system scales. Intermediate calculations are made to convert the units of water (from mm to MCM) and crop production (from kg/ha to Mkg), and to obtain recoverable flows from drainage and percolation. (The equations used to obtain these variables are provided in Chapter 4).

TABLE 12
Input data: size of the irrigation system (5 000 ha) and recoverable flow fractions in Iran (Islamic Republic of)

INTERMEDIATE RESULTS			
		Scenario	
		Reference	Intervention A
FIELD	Units		
Inflow total	(mm)	621	261
Outflow total	(mm)	621	261
SYSTEM			
Rainfall	(MCM)	8.6	8.6
Irrigation	(MCM)	22.5	4.5
Crop transpiration	(MCM)	19.1	9.3
Soil evaporation	(MCM)	3.3	2.5
Drainage	(MCM)	6.0	0.8
Percolation	(MCM)	2.8	0.6
Production	(Mkg)	26.6	16.0
Drainage total	(MCM)	6.0	0.8
Drainage, recoverable	(MCM)	4.2	0.5
Drainage, non-recoverable	(MCM)	1.8	0.2
Percolation, total	(MCM)	2.8	0.6
Percolation, recoverable	(MCM)	1.9	0.4
Percolation, non-recoverable	(MCM)	0.8	0.2
Inflow total	(MCM)	31	13
Outflow total	(MCM)	31	13

Source: Authors' own elaboration.

Table 13 shows the water accounting and water productivity results at field scale (farmer's perception) and the real impact at system scale. Real water savings is 10 percent, rather than the apparent savings of 26 percent. Water savings is much lower than expected, due to the influence of recoverable flows. Water productivity with intervention A (1.36 kg/m^3) is higher than the reference scenario (1.19 kg/m^3). This means that, although crop production with intervention A is lower than with the reference conditions, the water consumed with intervention A is much lower than the water consumed with the reference conditions.

TABLE 13

Results for REWAS tool: results field and results system in Iran (Islamic Republic of)

RESULTS			
		Scenario	
		Reference	Intervention A
RESULTS FIELD	Units		
Consumption, beneficial BC	(mm)	382	185
Consumption, non-beneficial NBC	(mm)	65	50
Return flows	(mm)	174	26
Storage change CS	(mm)	0.0	0.0
Water productivity WP	(kg/m^3)	1.19	1.36
Apparent water savings FWS	(mm)	-	163
Percentage of apparent Water Savings %FWS	**%**	**-**	**26%**
RESULTS SYSTEM			
Consumption, beneficial BC	(MCM)	19.1	9.3
Consumption, non-beneficial NBC	(MCM)	3.3	2.5
Return flows, recoverable RF	(MCM)	6.1	0.9
Return flows, non-recoverable NRF	(MCM)	2.6	0.4
Storage change CS	(MCM)	0.0	0.0
Water productivity WP	(kg/m^3)	1.19	1.36
Real water savings RWS	(MCM)	-	3.0
Percentage of real water savings %RWS	**%**	**-**	**10%**

Source: Authors' own elaboration.

Preventing non-recoverable return flows can lead to significant real water savings. Where there is saline groundwater, any deep percolation is unrecoverable. Box 4 discusses two examples of how non-recoverable flows can be recovered and where real water-savings efforts should focus.

BOX 4

Nonrecoverable return flows

Preventing nonrecoverable return flows can lead to significant real water savings. One type of nonrecoverable return flows is deep percolation in areas where there is saline groundwater. Shallow, salinewater tables are common over very large areas of public surfaceirrigation systems in China (such as He Tao, Dujiangyan, and most of the lower Yellow River systems, to name a few). Shallow, saline water tables are also present over about 30 percent of Punjab and likely much more in Sindh in Pakistan; and over parts of Punjab and Haryana in northern India. Efforts in real water savings in these cases should be focused on field interventions that reduce percolation flows and increase drainage flows – which may be recoverable. In REWAS, the recoverable flow fraction from percolation (RP) would be close to zero and the recoverable flow fraction from drainage (RD) would be relatively high given the environmental conditions.

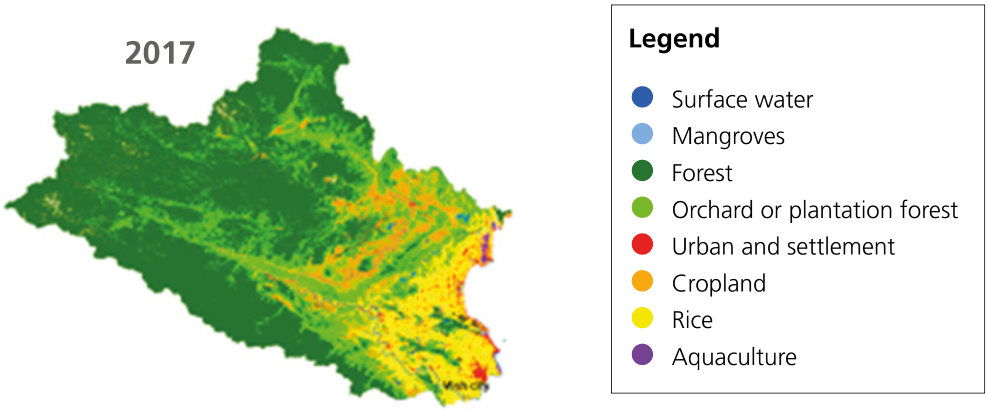
A second case where nonrecoverable flows can be recovered is water logging, which occurs in about 25 percent to 30 percent of the irrigation command area in Sindh. For the most part, this water is not recoverable as it sits in place and evaporates – resulting in a large nonbeneficial loss that limits agricultural yield in that region. This is more a result of poor (or more precisely, distorted) water management than application efficiency and field irrigation management per se – although they go hand in hand. The true nonrecoverable portion of water logging varies from place to place and pathway to pathway. Hence, it may not have the same potential for real water savings as is the case with highsaline water tables.

5.2. Irrigation system in the Ca basin, Viet Nam

The Ca River basin is a transboundary basin between Lao People's Democratic Republic (the) and Viet Nam. The basin is located in the north of both Viet Nam and Laos People's Democratic Republic (the). The water-accounting exercise focused on irrigated areas in the portion of the basin in Viet Nam, specifically in the Nghe An province, near the city of Vinh. Rice makes up the majority of vegetation cover. Rice paddies are defined as irrigated or flooded fields, or lowland paddy fields where rice is intensively planted for more than 1 cycle per year. Rice is planted in three seasons: Mua (or monsoon), He–Thu (or summer–autumn) and Dong–Xuan (or winter–spring). A typical vertical cross-section through a puddled rice field shows a layer of 0–0.10 m of ponded water.

The total area of the Nghe An province is 16 490 km². The province's eastern border is coastline, with high mountain ranges in the west. The monsoon tropical climate supports rich biodiversity. The total population of Nghe An was over 3.5 million in 2019. The total irrigated rice area is 1 520 km² (Figure 8).

FIGURE 8
Land use and irrigated rice production in the Nghe An province, Viet Nam



Source: Poortinga, A., Nguyen, Q., Tenneson, K., Troy, A., Saah, D., Bhandari, B., Ellenburg, W., Aekakkararungroj, A., Ha, L., Pham, H., Nguyen, G. & Chishtie, F. 2019. Linking Earth Observations for Assessing the Food Security Situation in Vietnam: A Landscape Approach. *Frontiers in Environmental Science*, 7. https://doi.org/10.3389/fenvs.2019.00186.

Note: Refer to the disclaimer on page ii for the names and boundaries used in this map.

Input data based on local measurements in paddy rice production for the growth season between February and June (winter–spring season) are shown in Table 14. Different outflows and crop yields are obtained for the reference irrigation application (910 mm) and for the intervention A irrigation application (182 mm). The inflows are rainfall and irrigation, and the outflows are crop transpiration, soil evaporation, drainage and percolation. Rainfall remains the same for each scenario (211 mm). For the reference scenario (irrigation at 910 mm), crop yield is 5 240 kg/ha, crop transpiration is 399 mm, drainage is 330 mm and percolation is 232 mm. In intervention A (irrigation at 182 mm), crop yield is significantly reduced to 3 813 kg/ha. The decrease in irrigation application results in a reduction in outflows and a decrease in crop yield.

TABLE 14
Input data for REWAS in Viet Nam

INPUT DATA			
		Scenario	
		Reference	Intervention A
FIELD	**Units**		
Rainfall	(mm)	211	211
Irrigation	(mm)	910	182
Crop transpiration	(mm)	399	230
Soil evaporation	(mm)	160	90
Drainage	(mm)	330	47
Percolation	(mm)	232	26
Yield	(kg/ha)	5240	3813

Source: Authors' own elaboration.

In Table 15, further input data is provided including the size of the irrigation system (5 000 ha) and the recoverable flow fraction. The recoverable flow fraction for drainage and percolation is assumed to be equal, at 90 percent.

TABLE 15
Input data: Size of the irrigation system (5 000 ha) and recoverable flow fractions in Viet Nam

SYSYEM			
Area	(ha)	5000	5000
RECOVERABLE FLOW FRACTION			
Recoverable drainage fraction RD	(%)	90%	90%
Recoverable percolation fraction RP	(%)	90%	90%

Source: Authors' own elaboration.

In Table 16, intermediate results for total inflows and total outflows are shown at field and system scales. Intermediate calculations are made to convert the units of water (from mm to MCM) and crop production (from kg/ha to Mkg), and to obtain recoverable flows from drainage and percolation. (The equations used to obtain these variables are provided in Chapter 4).

TABLE 16

Intermediate results using REWAS tool: field, system and recoverable flows in Viet Nam

INTERMEDIATE RESULTS			
		Scenario	
		Reference	Intervention A
FIELD	Units		
Inflow total	(mm)	1121	393
Outflow total	(mm)	1121	393
SYSTEM			
Rainfall	(MCM)	10.6	10.6
Irrigation	(MCM)	45.5	9.1
Crop transpiration	(MCM)	20.0	11.5
Soil evaporation	(MCM)	8.0	4.5
Drainage	(MCM)	16.5	2.4
Percolation	(MCM)	11.6	1.3
Production	(Mkg)	26.2	19.1
Drainage, total	(MCM)	16.5	2.4
Drainage, recoverable	(MCM)	14.9	2.1
Drainage, non-recoverable	(MCM)	1.7	0.2
Percolation, total	(MCM)	11.6	1.3
Percolation, recoverable	(MCM)	10.4	1.2
Percolation, non-recoverable	(MCM)	1.2	0.1
Inflow total	(MCM)	56	20
Outflow total	(MCM)	56	20

Source: Authors' own elaboration.

Table 17 shows the water accounting and water productivity results at field scale (farmer's perception) and real impact at system scale for Viet Nam. Real water savings is 11 percent, rather than the apparent savings of 50 percent. Similar to the example in Table 13, the percentage of water savings is much lower than expected due to the influence of recoverable flows. Water productivity with intervention A (1.19 kg/m^3) is higher than in the reference scenario (0.94 kg/m^3). This means that, even with intervention A, crop production is lower compared to the reference conditions, and the water consumed with intervention A is much lower than the water consumed in the reference scenario.

TABLE 17

Results with REWAS tool: field- and system-level results in Viet Nam

RESULTS			
		Scenario	
		Reference	Intervention A
RESULTS FIELD	Units		
Consumption, beneficial BC	(mm)	399	230
Consumption, non-beneficial NBC	(mm)	160	90
Return flows	(mm)	562	73
Storage change CS	(mm)	0	0
Water productivity WP	(kg/m^3)	0.94	1.19
Apparent water savings FWS	(mm)	-	559
Percentage of apparent water savings %FWS	**%**	**-**	**50%**
RESULTS SYSTEM			
Consumption, beneficial BC	(MCM)	20.0	11.5
Consumption, non-beneficial NBC	(MCM)	8.0	4.5
Return flows, recoverable RF	(MCM)	25.3	3.3
Return flowsnon-recoverable NRF	(MCM)	2.8	0.4
Storage change CS	(MCM)	0.0	0.0
Water Productivity WP	(kg/m^3)	0.94	1.19
Real water savings RWS	(MCM)	-	5.9
Percentage of real water savings %RWS	**%**	**-**	**11%**

Source: Authors' own elaboration.

References

Droogers, P. & Bouma, J. 2014. Simulation modelling for water governance in basins. *International Journal Of Water Resources Development*, 30(3): 475–494. https://doi.org/10.1080/07900627.2014.903771

Droogers, P., Immerzeel, W. W., Terink, W., Hoogeveen, J., Bierkens, M. F. P., Beek, L. P. H. van & Debele, B. 2012. Water resources trends in Middle East and North Africa towards 2050. *Hydrology and Earth System Sciences*, 16(9), 3101–3114. https://doi.org/10.5194/hess-16-3101-2012

Droogers P., Kaune A., van Opstal J., Steduto P. & Perry C. (forthcoming). *Crop water productivity options to achieve real water savings – Training Manual*. Bangkok, FAO.

FAO. 2012. *Coping with water scarcity – An action framework for agriculture and food security*. FAO Water Reports, No. 38. Rome. http://www.fao.org/3/i3015e/i3015e.pdf

Fereres, E. & Soriano, M, A. 2007. Deficit irrigation for reducing agricultural waste. *Journal of Experimental Botany*, 58(2), 147-159. https://doi.org/10.1093/jxb/erl165

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A. & Michaelsen, J. 2015. The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data*, 2: 150066. https://doi.org/10.1038/sdata.2015.66

Hellegers, P., Immerzeel, W. & Droogers, P. 2013. Economic concepts to address future water supply–demand imbalances in Iran, Morocco and Saudi Arabia, J. *Hydrology*, 502: 62–67. https://doi.org/10.1016/j.jhydrol.2013.08.024

Hong, N. B. & Yabe, M. 2017. Improvement in irrigation water use efficiency: a strategy for climate change adaptation and sustainable development of Vietnamese tea production. *Environment, Development and Sustainability*, 19(4): 1247–1263. https://doi.org/10.1007/s10668-016- 9793-8

Howell, T. A. 1990. Relationships between crop production and transpiration, evapotranspiration, and irrigation. *Agronomy*, 30: 391–434.

Iran Statistical Center. n.d. *Iran Statistical Center*, [Cited 24 March 2020] https://www.amar.org.ir/en/

Jha, A. K., Malla, R., Sharma, M., Panthi, J., Lakhankar, T., Krakauer, N. Y., Pradhanang, S. M., Dahal, P. & Shrestha, M. L. 2016. Impact of Irrigation Method on Water Use Efficiency and Productivity of Fodder Crops in Nepal. *Climate*, 4(1), 4, https://doi.org/10.3390/cli4010004

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M.A. & Kijne, J. 2010. Improving agricultural water productivity: Between optimism and caution, *Agricultural Water Management*, 97(4): 528-535. https://doi.org/10.1016/j.agwat.2009.03.023

Oweis, T. & Hachum, A. 2005. Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa, *Agr. Water Manag.*, 80(1): 57–73. https://doi.org/10.1016/j.agwat.2005.07.004

Perry, C. 2011. Accounting for water use: terminology and implications for saving water and increasing production. *Agr. Water Manag.* 98, 1840–1846. https://doi.org/10.1016/j.agwat.2010.10.002

Perry, C. 2007. Efficient Irrigation; Inefficient Communication; Flawed Recommendations. *Irrigation and Drainage*, 56: 367-378. https://doi.org/10.1002/ird.323

Schneider, P., Sander, B.O., Wassmann, R. & Asch, F. 2019. Potential and versatility of WEAP model (Water Evaluation and Planning System) for hydrological assessments of AWD (Alternate Wetting and Drying) in irrigated rice. *Agr. Water Manag.*, 224: 105559. https://doi.org/10.1016/j.agwat.2019.03.030

Steduto, P., Hsiao, T.C., Fereres, E., and Raes, D. 2012. *Crop yield response to water. FAO Irrigation and Drainage Paper*, No. 66. Rome, FAO.

Van Opstal, J., Droogers, P., Kaune, A., Steduto, P. and Perry, C. 2021. *Guidance on realizing real water savings with crop water productivity interventions*. Wageningen, FAO and FutureWater. https://doi.org/10.4060/cb3844en

ISBN 978-92-5-139240-9

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CD2914EN/1/08.25