Food and Agriculture Organization of the United Nations

Reuse of water in agricultural systems
Follow the Water

Second edition

FutureWater

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Abstract

Potential water savings by implementing advanced irrigation technologies have in many cases not been achieved and have even led to higher water consumption by irrigators. This has been to the advantage of farmers concerned (more crop produced), but has been disappointing to planners who were hoping to save water (in fact, making it available for other uses). Ignoring return flows and reuse of water are the main reasons for these underperforming water savings projects.

The current study attempts to quantify reuse rates in irrigated agricultural systems. A database on return flows and reuse of water is developed based on an extensive literature review. The key finding is that that knowledge, information, and data on reuse of water in irrigated agriculture is poor. Based on the limited data, return flows are in the order of 30 percent to 50 percent in irrigation systems.

The Follow the Water approach as introduced in this report was developed to support the tracking of water flows between irrigation systems and irrigation blocks. The accompanying Follow the Water tool can be used for the quick initial analysis of impacts of interventions and as an education and training instrument.

The main recommendation from the current study is that proposed interventions in irrigation technologies should be based on the Follow the Water approach.

This publication was developed under the Asia-Pacific Water Scarcity Programme (WSP), a regional initiative led by the Food and Agriculture Organization of the United Nations. The WSP supports countries to strengthen their capacity to manage water scarcity through an adaptive, country-led process encompassing in-depth policy and governance analyses, regional mapping of water scarcity trends, assessment of modeling capabilities, water tenure analyses, and consistent engagement with national, regional, and local governments as well as water stakeholders. As part of Phase I of the WSP, technical experts in Thailand, Viet Nam, Cambodia, Indonesia, Lao People's Democratic Republic, and Mongolia were trained to conduct water accounting in agricultural systems at different scales using tools that included Follow the Water and REal WAter Savings (REWAS).

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1. Relevance

1.1 Global water use and consumption

The agriculture sector demands and consumes more water than any other sector. Globally, it is responsible for more than 85 percent of all human-induced water withdrawals (D'Odorico *et al.*, 2020). Borsato *et al.* (2020) reported that agriculture is the major player in the human abstraction of water resources and reported that about 70 percent of global freshwater withdrawals is used for irrigation to sustain global crop production. Other studies on global water use in agriculture agree that water use for agriculture is between 70 percent and 85 percent of total global water use.

The World Bank (2022) reports that this abstraction of water is a critical input for agricultural production and plays an important role in food security. It notes that irrigated agriculture accounts for about 20 percent of the total cultivated land and contributes 40 percent of the total food produced worldwide.

An increase in water use over recent decades has led to water scarcity in many countries. This trend will continue as the gap between water demand and supply is projected to widen as a result of factors such as population growth and economic development (Dinar, Tieu and Huynh, 2019), and environmental factors such as land degradation (IPCC, 2019) and climate change (Turral, Burke and Faures, 2011). Solutions to reverse this trend should focus on irrigated agriculture as irrigation is the largest consumer of freshwater withdrawals in almost all water-scarce regions.

Unfortunately, solutions to overcome the current and future 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) suggestions have been identified over the last 20 years (Grafton *et al.*, 2018; Molden *et al.*, 2010; Opstal *et al.*, 2021; Perez-Blanco, Hrast-Essenfelder and Perry, 2020, among others). However, uptake of these new insights by decision-makers and the irrigation sector itself has been limited.

One of the major misconceptions is that by investing in more efficient irrigation technologies such as sprinkler or drip technologies, water savings will follow automatically. This assumption has been proven incorrect in many studies on water saving projects. Indeed, many such projects have severely underperformed and did not achieve their intended goals. In some cases not only were projected savings never achieved, they even led to higher water consumption. This misconception that more efficient irrigation technologies will automatically lead to water savings can also be easily debunked by logical reasoning: farmers are unlikely to invest heavily in an irrigation system that leads to the farmer getting less water.

The distinction between water **withdrawal** and water **consumption** is key in understanding potential water savings (Box 1). Although this distinction between withdrawals and consumption might seem somewhat academic, it is important for a better understanding of irrigation systems. Moreover, it is key in all aspects of irrigation design, planning, management and rehabilitation (Perry and Steduto, 2017; Scheierling and Tréguer, 2018).

BOX 1

Withdrawal versus consumption

The unique characteristics of water that distinguish it from most other resources and commodities need to be kept in mind in any discussion of the role of water use in irrigated agriculture. These include water's mobility and variable supply and that it is rarely completely consumed during its use. In irrigated agriculture, it is not unusual for half of the water withdrawn for irrigation to be returned to the hydrologic system as return flows—upon which downstream users may increasingly rely as water becomes scarcer.

These characteristics add to the complexity surrounding the use of water and the improvement of its use and require several distinct measures of water quantity. Water withdrawn from a source, water applied to the place of use (such as a farm), and water consumed (also called evapotranspiration in irrigated agriculture) are key measures. Return flows are the difference between water withdrawn and water consumed.

Source: Scheierling, S.M., & Tréguer, D.O. 2018. *Beyond crop per drop: assessing agricultural water productivity and efficiency in a maturing water economy*. [online]. [Cited 2 February 2022]. https://doi.org/10.1596/978-1-4648-1298-9

BOX 2

Efficiency versus fractions

The terms "irrigation efficiency" and "losses" tend to confuse planners and policy-makers involved in addressing issues of water scarcity. Even irrigation professionals use various terms interchangeably and without due regard for the clarity of their recommendations.

A clear and transparent framework has therefore been promoted over recent decades under various terms (e.g. water accounting, Reuse of Water in Agricultural Systems (REWAS), Follow The Water). This framework is based on hydrological principles applied to the irrigation sector.

The framework is that water diverted to irrigation schemes can be divided into the following:

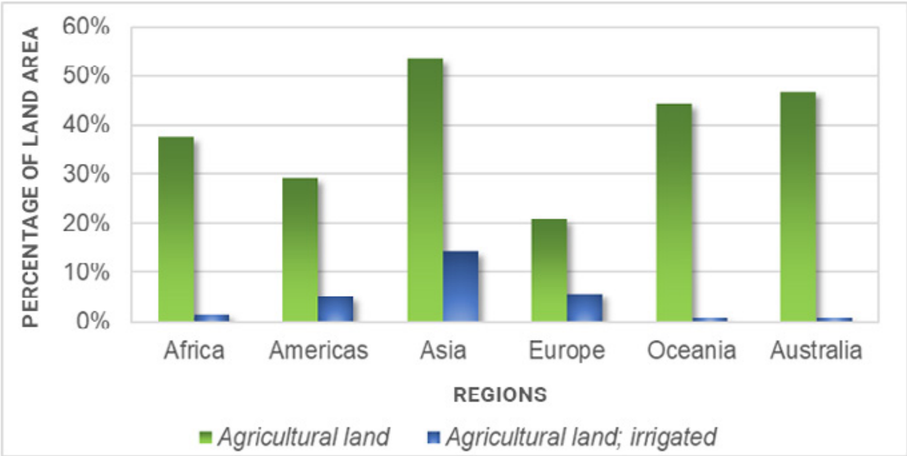
- The consumption (essentially ET), comprising:
    - **beneficial consumption** (for the purpose intended or other beneficial use such as environmental purposes);
    - **non-beneficial consumption** such as weeds or resulting from capillary rise during a fallow period).
- The return flows[a], comprising:
    - **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).

Source: Perry, C. 2007. Efficient irrigation; inefficient communication; flawed recommendations. *Irrig. Drain.* 56, 367–378. [online]. [Cited 22 March 2022]. https://doi.org/10.1002/ird.323

[a] The original term used for "return flows" was "non-consumed fraction". This, however, led to impractical definitions such as "non-recoverable non-consumed flows". To ease communication, we use "return flows" and their subdivision into "recoverable return flows" and "non-recoverable return flows", which is probably easier to grasp.

On a global scale, about 3 500 km^2 of land is irrigated. The total agricultural area that is actually equipped with any kind of irrigation system amounts to about 7 percent according to FAOSTAT (FAO, 2025a). Large differences between continents and countries in areas equipped for irrigation exist (Siebert *et al.*, 2013). For example, in Asia over 50 percent of the agricultural land is irrigated, whereas in Europe it is about 20 percent (Figure 1). Asian countries have the largest areas in the world equipped for irrigation (Figure 2).

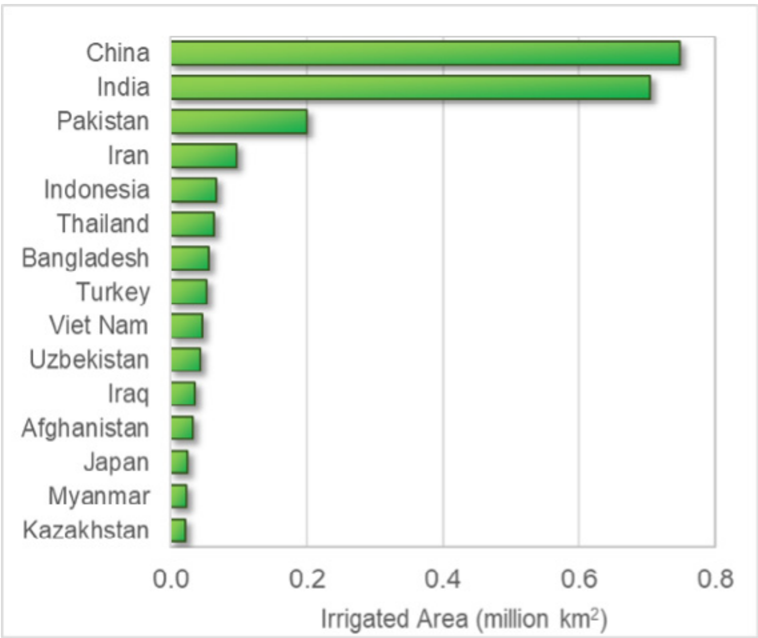
FIGURE 1
Area equipped for irrigation per continent



Source: FAO. 2025. FAOSTAT.: Land Use.[Accessed on 29 March 2020]. https://www.fao.org/faostat/en/#data/RL. Licence: CC-BY-4.0.

Note: Top: in km^2; bottom as percentage of total land area. In these numbers the entire Russian Federation is included in Europe and excluded from Asia. The entire Russian Federation covers about 16 million km^2, of which about 23 percent is located in Europe.

FIGURE 2
Countries with the largest areas equipped for irrigation



Source: FAO. 2025. FAOSTAT.: Land Use.[Accessed on 29 March 2020]. https://www.fao.org/faostat/en/#data/RL. Licence: CC-BY-4.0.

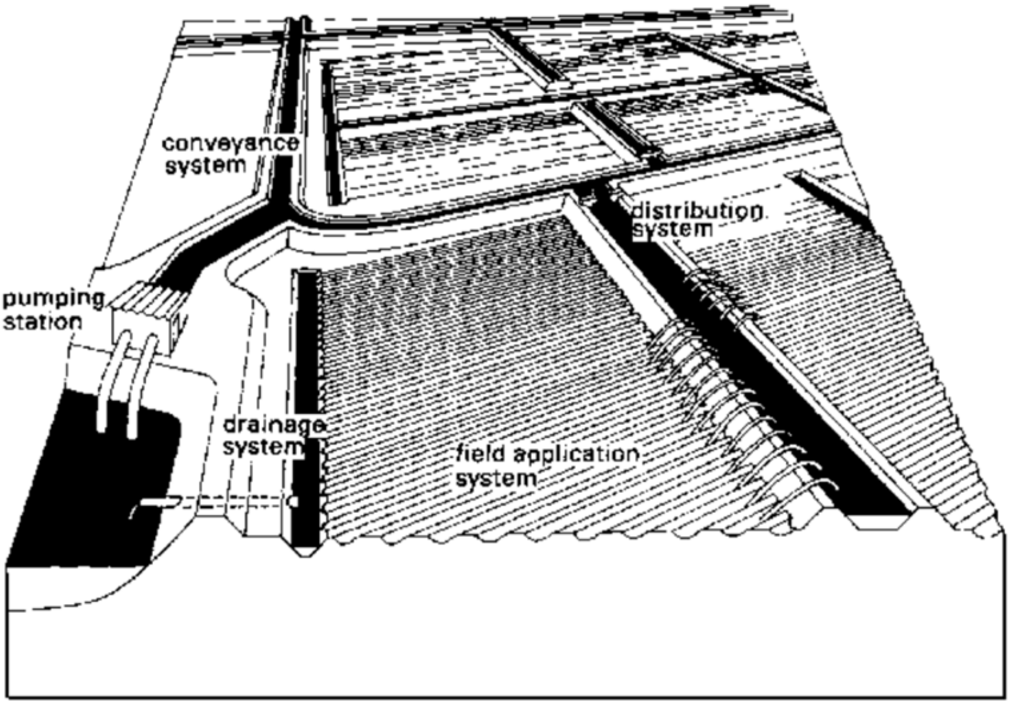
1.2 Irrigation systems

The basic concept of any irrigation systems consists of an intake structure, a conveyance system, a distribution system, a field application system, and a drainage system (Brouwer, Goffeau and Heibloem, 1985). These are briefly described here:

- The **intake structure** is built at the entry to the irrigation system. Its purpose is to direct water from the original source of supply (lake, river, reservoir etc.) into the irrigation system. In some cases, the irrigation water source lies below the level of the irrigated fields. Then a pump must be used to supply water to the irrigation system. Groundwater pumping can also be considered to be an intake structure.
- The **conveyance system** ensures the transport of water from the main intake structure or main pumping station up to the field ditches.
- The **distribution system** ensures the transport of water through field ditches to the irrigated fields.
- The **field application system** ensures the transport of water within the fields. There are three basic methods: surface irrigation (furrow, border, basin), sprinkler irrigation and drip irrigation.
- The **drainage system** removes the excess water from the irrigated land. This excess water may be, for example, waste water from irrigation or surface runoff from rainfall. It may also include leakage or seepage water from the distribution system.

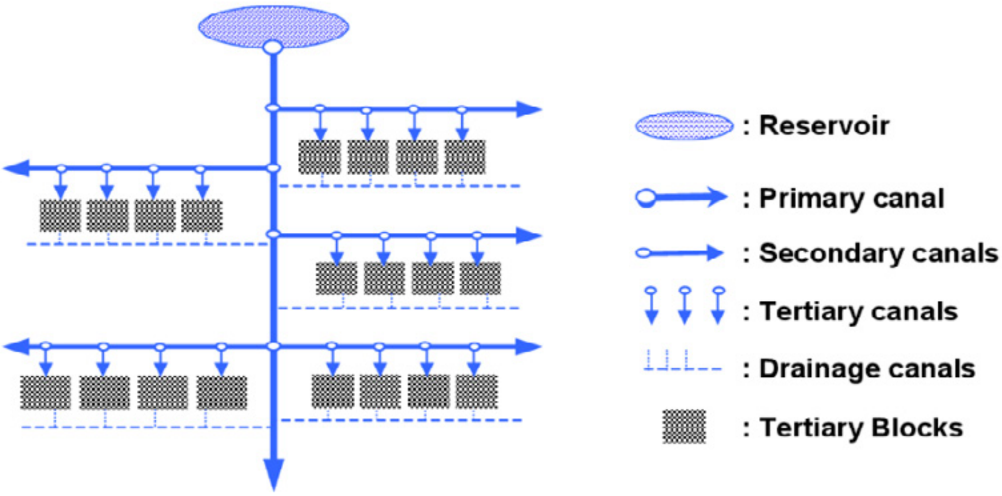
Some of these components are shown in various graphic forms in Figure 3, Figure 4 and Figure 5.

FIGURE 3
Classic drawing of irrigation system



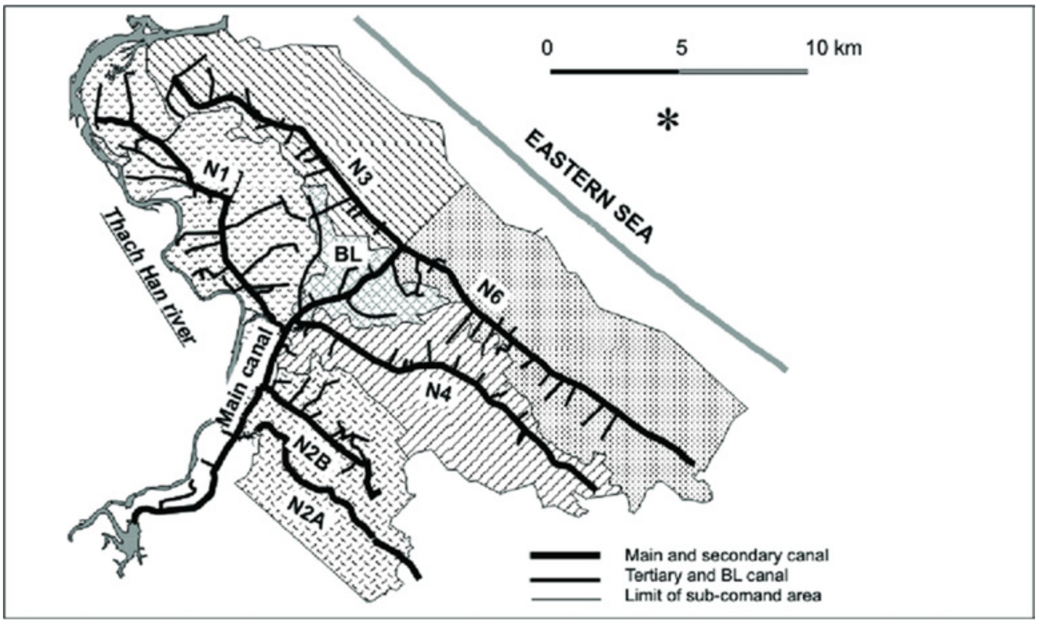
Source: Brouwer, C., Goffeau, A., & Heibloem, M. 1985. *Irrigation water management: training manual No. 1 - Introduction to irrigation.* Rome, FAO. (also available at https://www.fao.org/3/r4082e/r4082e00.htm).

FIGURE 4
Schematic layout of an irrigation system



Source: Hellegers, P.J.G.J. 2006. The role of economics in irrigation water management. *Irrig. Drain.* 55, 157–163. [online]. [Cited 22 February 2022]. https://doi.org/10.1002/ird.223

FIGURE 5
Example of a realistic irrigation system layout: The Nam Thach Han irrigation system, Quang Tri Province located in Central Viet Nam



Source: Hussain, I. 2007. Pro-poor intervention strategies in irrigated agriculture in Asia: Issues, lessons, options and guidelines. *Irrigation and Drainage*, 56 (2-3). [online]. [Cited 21 February 2022]. https://doi.org/10.1002/ird.299

BOX 3

FAO and irrigation

FAO has been very active in developing technical training manuals and guidelines on irrigation design, construction and use. Many of those manuals and guidelines are still used, along with the concepts they promote. The most relevant manuals and guidelines are:

- FAO. 1985. Irrigation water management: training manual No. 1. Introduction to irrigation. https://www.fao.org/3/r4082e/r4082e00.htm
- FAO. 1986. Irrigation water management: training manual No. 3. Irrigation water needs. https://www.fao.org/3/S2022E/s2022e00.htm
- FAO. 1989. Irrigation water management: training manual No. 4. Irrigation scheduling. https://www.fao.org/3/t7202e/t7202e00.htm
- FAO. 1988. Irrigation water management: training manual No. 5. Irrigation methods. https://www.fao.org/3/S8684E/s8684e00.htm
- FAO. 1999. Modern water control and management practices in irrigation: impact on performance. Water Reports 19. https://www.fao.org/3/bl889e/bl889e.pdf
- FAO. 2007. Modernizing irrigation management: the MASSCOTE approach. Mapping system and services for canal operation techniques. FAO Irrigation and Drainage Paper 63. https://www.fao.org/3/a1114e/a1114e.pdf

Source: Authors' own elaboration.

2. Concepts of return flows

2.1. Definitions and processes

Distinguishing consumptive and non-consumptive (return flows) portions of water use is a key foundation of water reuse analyses and potential water "savings".[1] The non-consumed flow from a water user enters a network of hydrological flow paths and may be captured and used at another location. Water reuse is defined as the downstream use of non-consumed water that was previously withdrawn upstream (Simons, 2021). Reuse can take place through withdrawals from surface or groundwater for purposes such as agricultural and landscape irrigation, industrial processes, domestic use, aquaculture, and the environment. The effects of rainfall are excluded from this concept, making it especially applicable to blue water[2] uses in general, of which irrigated agriculture is globally the largest.

In agricultural systems, downstream reuse often occurs unplanned and does not necessarily involve a treatment process. It occurs within and between irrigation systems, facilitated by both natural and man-made pathways, mostly invisible to water managers, and therefore largely disregarded in water distribution mechanisms. Complex networks of water reuse can develop, encompassing many irrigation units or farmers, and occurring through surface water as well as groundwater resources.

Water reuse in agriculture can also be planned and regulated, particularly when it is applied as a non-conventional freshwater source to alleviate water scarcity. In those cases, non-consumed flows are managed and transported through hydraulic infrastructure, often involving treatment processes.[3]

This guidance document relates to unplanned as well as planned water reuse, as in both cases similar challenges are faced by agricultural water managers in taking scale-dependent impacts and trade-offs into account.

2.2. Follow the Water: scale dependency and impacts on water consumption

Water reuse in irrigation challenges the application of the classical irrigation efficiency concept when looking beyond field scale (Jensen, 2007). Increasing water consumption relative to supply, thus effectively retaining and consuming water that previously returned to surface or groundwater resources, will reduce water supply to any downstream users. For appropriate and sustainable management of irrigation systems it is therefore highly important to take into account the volumes and dynamics of return flows.

Incorporating water reuse in agricultural water management strategies and processes starts with the distinction between consumed and non-consumed flows. This report makes use of the concepts of the simplified Follow the Water approach, which is based on the work of Perry (2011) and summarized by Opstal *et al.* (2021). This conceptual framework (Figure 6) dictates that water diverted to irrigation schemes can be divided into the two main components:

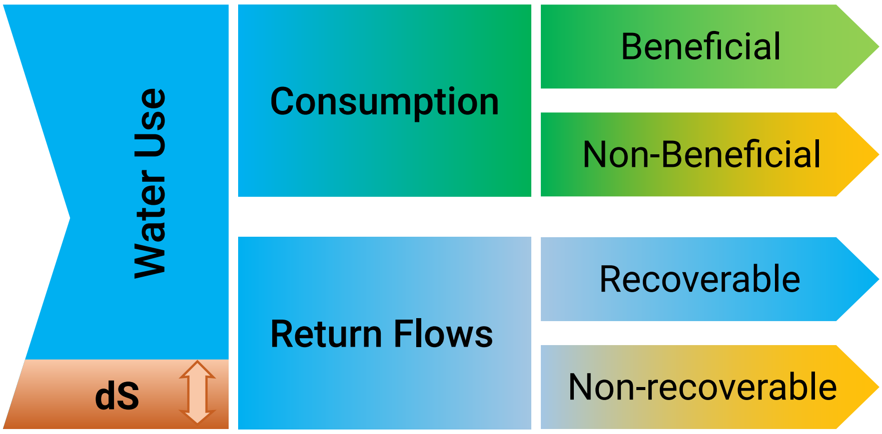
1 We put "savings" in inverted commas here since what is actually meant is "making available for other uses". In cases where water is actually saved in a reservoir, the term "stored" will be used.

2 Streamflow and groundwater.

3 Most commonly in Asia, the reuse of untreated or partially treated wastewater from urban settlements.

- The consumed fraction,[4] comprising:
  - Beneficial consumption (for the purpose intended or another beneficial use);
  - Non-beneficial consumption (such as by weeds, evaporation from wetted surfaces, or capillary rise during a fallow period).
- The return flow fraction, comprising:
  - Recoverable flows (water flowing to drains and back into the river system for possible diversion downstream, and percolation to freshwater aquifers);
  - Non-recoverable flows (percolation to saline aquifers, outflow to drains that have no downstream diversions or direct outflow to the ocean).

FIGURE 6
The Follow the Water conceptual framework



Source: Adapted from Van Opstal, J., Droogers, P., Kaune, A., Steduto, P. and Perry, C. 2021. *Guidance on realizing real water savings with crop water productivity interventions.* FAO Water Reports 46. Wageningen, FAO and FutureWater. https://doi.org/10.4060/cb3844en; Perry, C. 2011. Accounting for water use: terminology and implications for saving water and increasing production. Agric. *Water Manag.* 98(12): 1840–1846. https://doi.org/10.1016/j.agwat.2010.10.002.

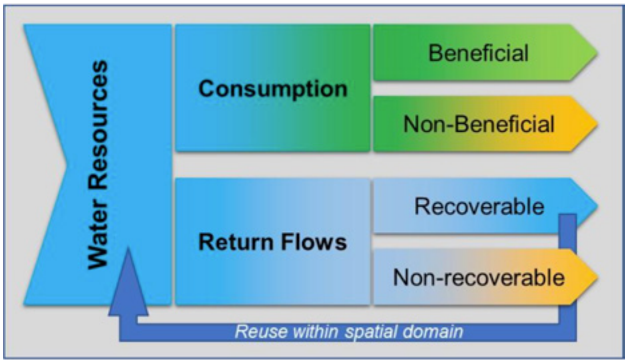
The term dS in Figure 6 refers to changes in storage in the system. These can be negative (diversions > consumptions + return flows) or positive. Over longer time periods this usually is zero, unless unsustainable aquifer pumping is practiced.

The key component that needs to be tracked to effectively Follow the Water is the recoverable return flow. Reuse of this recoverable water can occur within the spatial domain of interest (for example an irrigation system) or further downstream. In the former case, the recoverable return flow effectively enhances water availability at the system scale, whereas the original diversion at the system head or inlet does not change. Thus, the system-scale beneficial consumed fraction increases and the overall irrigation system can be considered as more efficient in terms of water use, thanks to the occurrence of water reuse (recoverable return flows within the system).

To understand the implications of water reuse for agricultural water management, it is relevant to further explore the scale dependency of the consumed fraction resulting from water reuse. In this regard the spatial domain of interest is used for this scale dependency. In other words, if a field is chosen as the spatial domain of interest, all return flows from that field are considered as external return flows. In contrast, if an irrigation system is considered as the spatial domain of interest, return flows from one particular field might be reused (for example groundwater pumping of seepage water, or reuse of water in drains) is considered as internal return flows (Figure 7).

[4] Fractions and percentages are used interchangeably in this publication. So a consumed fraction of, for example, 0.4 is also noted as 40 percent.

FIGURE 7
The basic Follow the Water conceptual framework and the scale dependency reuse fraction within the spatial domain of analysis



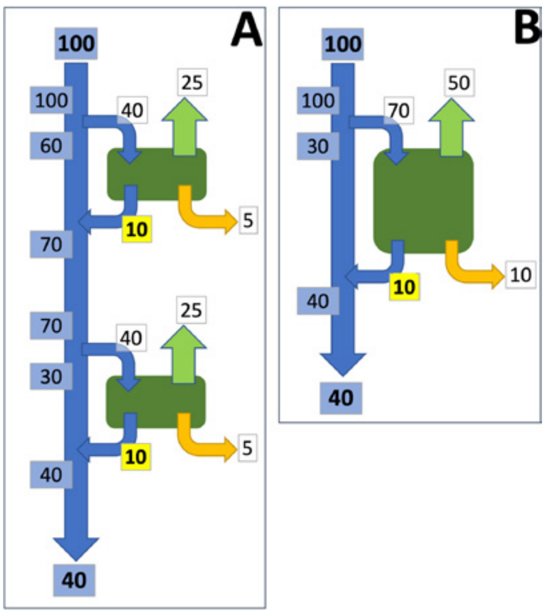
Source: Adapted from Van Opstal, J., Droogers, P., Kaune, A., Steduto, P. and Perry, C. 2021. *Guidance on realizing real water savings with crop water productivity interventions.* FAO Water Reports 46. Wageningen, FAO and FutureWater. https://doi.org/10.4060/cb3844en; Perry, C. 2011. Accounting for water use: terminology and implications for saving water and increasing production. Agric. *Water Manag.* 98(12): 1840–1846. https://doi.org/10.1016/j.agwat.2010.10.002.

This spatial domain dependency of the return flow is schematically presented in Figure 8. The network A and B are the same. For A, two irrigation blocks are included that are aggregated in schematic B. For the rest, all numbers are the same: 100 units of water flowing into the canal, 40 units are outflow, 50 units are consumed (for example crop evapotranspiration), and 10 units are non-recoverable return flows.

The interesting part is that the recoverable return flows for schematic A are 20 units, whereas for schematic B they are 10 units. The reason behind this is that for schematic A the 10 units from the upstream irrigation block that are reused by the downstream block are shown separately. In schematic B this is internally accounted for.

This phenomenon that the return flow depends on the spatial domain of interest has led to much confusion and is the core of the many false water savings.

FIGURE 8
Schematic representation of internal and external reuse as function of the spatial domain considered



Source: Authors' own elaboration.

In **Figure 8**, A shows two separate water use systems whereas B shows the same two systems but aggregated into one. Recoverable returns flows are 20 and 10 respectively for A and B. Return flow fractions are 20 percent (20/100) for A and 10 percent (10/100) for B. The numbers used here are dimensionless and only illustrative.

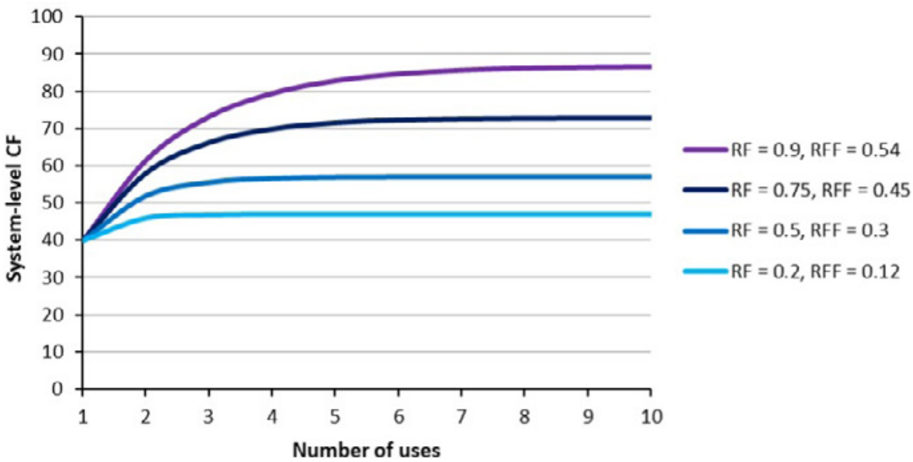
A more theoretical analysis of this spatial dependency of the return flow fraction is presented in Figure 9. The figure plots the consumed fraction for an irrigation system, assuming different recoverable return flow fractions. Classical efficiency of individual water users was chosen to be 40 percent, assumed as a reasonable value for surface irrigation efficiency (Brouwer, Prins and Heibloem, 1989). Each line corresponds with a different recoverable fraction for the users across the system. Thus, each user discharges 60 percent of its supply back to the system; however the actual portion of this return flow that is available and suitable for reuse differs in each case. For illustration purposes, it is assumed that it is a cascade system where downstream users have no other source of irrigation water than return flows from upstream users.

Figure 9 shows that the system-scale consumed fraction does increase with water reuse, but that the recoverable return flow fraction is key in determining the extent to which consumption increases with scale (spatial domain of interest). Depending on the recoverable fraction, a maximum value for consumed fraction is approached after roughly two to six cycles of reuse. Even when recoverable return flows are high, water must be reused at least three or four times before a value of 70 percent to 80 percent is reached. This theoretical analysis gives an idea of the extent to which water reuse can affect system-level efficiency, and how high consumption values can be achieved even for surface irrigation systems commonly regarded as wasteful.

In Figure 9, the CF of individual users is assumed to be 0.4.

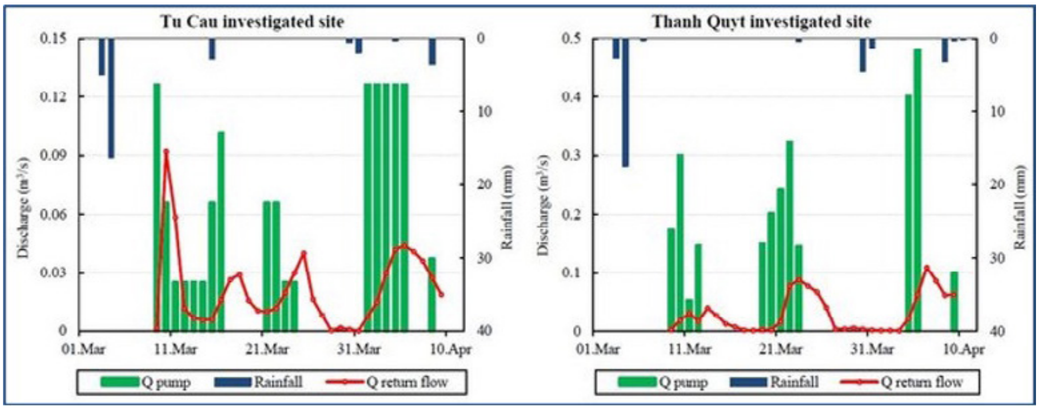
FIGURE 9

Increase of system consumed fraction (CF) with rate of water reuse, for different recoverable fraction (RF) values and the corresponding return flow fraction (RFF)



Source: Simons, G.W.H., Bastiaanssen, W.G.M., & Immerzeel, W.W. 2015. Water reuse in river basins with multiple users: A literature review. J. Hydrol. 522, 558–571. [online]. [Cited 20 February 2022]. https://doi.org/10.1016/j.jhydrol.2015.01.016

FIGURE 10
A typical example of time dependency of return flows



Source: Van, T.T.H., Viet, T.Q., & Ribbe, L. 2017. *Reuse potential of return flow for irrigating paddy farms in the Vu Gia Thu Bon Delta. J. Int. Sci. Publ.* 5, 346–360.

The appreciation of recoverable return flows within or outside the spatial domain of interest often leads to confusing or even questionable decision making. A typical example can be found in the final report of the 2015 Asian Development Bank supported study, India: Innovations for More Food with Less Water. Technical Consultant's Report. Final Report, which states:

- water use assessments should include any reuse of water taking account of any use or reuse of seepage or other conveyance, distribution or application losses as conventionally described that might subsequently be used by farmers **within** the boundaries of the irrigation scheme. (p.10).

In other words: all return flows not used within the irrigation scheme itself should be considered as a loss and should be reduced. It is clear that this contradicts the Follow the Water approach and might lead to unnecessary investments and even negative impacts on downstream users outside the irrigation scheme under study.

Besides return flows being dependent on the spatial domain, time dependency of return flows is in most cases also highly variable (Van, Viet and Ribbe, 2017). A typical example is presented in Figure 10 where daily variations in return flows in the dry season for two irrigation blocks in the Vu Gia Thu Bon Delta in Central Viet Nam are presented. In Figure 10, the border or basin irrigation is on the left and the overhead irrigation is on the right.

Obviously, a clear correlation between irrigation applications and return flows can be observed. Changes in irrigation systems, for example improving from border to sprinkler, is to a large extent related to this time dependency. With pressurized irrigation systems, daily variation in irrigation applications is lower, resulting in lower return flows. The result will, in many cases, be higher consumption and lower return flows. The first one being positive for the farmer concerned, the latter potentially negative for downstream users.

A recent study on return flows from irrigation in alluvial valleys discussed a theoretical approach to groundwater recharge and impact on timing of return flows (Ferencz and Tidwell, 2022). The publication started with a very clear section on the main challenges and opportunities regarding return flows:

- Irrigation can be a significant source of groundwater recharge in many agricultural regions, particularly in arid and semi-arid climates. Once infiltrated, irrigation recharge can travel via subsurface flow paths that return to the river system in a lagged manner, supplementing natural streamflow weeks, months, or even years from when the irrigation was applied.

> In regions that experience low flows during summer and early fall, return flows can be a significant source of supplementary streamflow. Many water planning and operations models either ignore return flows or roughly approximate them with analytical solutions. Thus, return flows represent an important but often overlooked component of the hydrological exchange and overall water balance in agricultural regions. (p.1)

Another study from the United States of America evaluated irrigation efficiencies in Montana and the impact on reuse and return flows (Lonsdale and Cross, 2020). The study concluded that moving from the still very common flood irrigation to sprinkler irrigation the potential outcomes will be:

- reduced aquifer recharge;
- reduced groundwater contribution to streamflow;
- more water in stream at the time and place of diversion; and
- potential increase in consumptive use at watershed scale.

The study also mentioned that 10.5 million acre-feet of water per year is diverted for irrigation, and 2.6 million acre-feet of that water is consumed by crops and that it is important to understand what is happening with the nearly 8 million acre-feet of water that is diverted but not consumed. The study concluded that a goal for Montana's water management was to support aquifer recharge by maintaining unlined canal infrastructure.

Diminishing water quality of return flows can be an important factor to take into consideration. In this guidance the impact of return flows on water quality will not be further discussed. However, a recent study (Ator, Miller and Saad, 2022) in three river basins in the United States of America concluded that the relatively high concentrations of nitrogen, phosphorus and dissolved solids were in most cases not from wastewater return flows. Consequently, efforts to reduce wastewater nutrient effluent would likely have minimal impact on regional ecological conditions. The study concluded that deteriorating water quality as a result of return flows is very location specific and should be analysed case by case.

2.3. Tools and models available

Table 1 presents an inventory of existing tools and models relevant for the Follow the Water approach. Each of these tools is evaluated in Table 2 according to five key criteria:

- **Scale**: In order to address the scale-dependent issues of efficiencies and water reuse set out in the previous sections, a tool should be able to look at the scale of an irrigation system and distinguish between the main components of such a system.
- **Irrigation focus**: This refers to the degree to which the tool has been developed with the specific characteristics of irrigation systems in mind.
- **Complexity**: This refers to the level of complexity a user needs to deal with when operating the tool, for example in terms of understanding the processes being simulated within the model.

- **Use (suitability):**
  - Practitioners: the extent to which agricultural water managers can be considered part of the target audience of the tool. Typically, the tools with lower ranking here have been developed more with the scientific community in mind.
  - Training: the degree to which the tool can be easily applied in workshops and courses (for example intuitive user interface, existing and accessible training material).
  - Awareness: suitability for demonstration of the impact changes in irrigation practices have on water consumption and return flows.

From the existing tools that are available to analyse agricultural water management practices, none properly addresses the irrigation system scale and at the same time is simple enough and applicable for practical decision-makers. It is this gap which needs to be filled by the Follow the Water tool (described in Section 2.4).

TABLE 1
List of existing tools for assessing water flows in irrigation systems

Name	Description	References
CROPWAT	Used to calculate crop water requirements and irrigation requirements based on soil, climate and crop data	https://www.fao.org/land-water/databases-and-software/cropwat/en/
AQUACROP	AquaCrop is the crop growth model developed by FAO to address food security and assess the effect of the environment and management on crop production	https://www.fao.org/land-water/databases-and-software/aquacrop/en/
NaanCAT	Advanced irrigation design software	https://naandanjain.com/download-irrigation-software/
IrriRT	Software used to design irrigation systems for landscaping, gardening, residential turf and parks	https://www.irriworks.com/
Wasim	A one-dimensional soil water balance model that allows irrigation to be scheduled according to rules, water table position to be simulated with field under drainage, and soil water salinity to be estimated	https://cord.cranfield.ac.uk/articles/software/Wasim_soil_water_balance_model_/8223491
SWAP	SWAP (Soil, Water, Atmosphere and Plant) simulates flow and transport processes at field-scale level, during growing seasons and for long-term time series	https://www.swap.alterra.nl/
IrriCad	Software for the design of all types of pressurized irrigation systems from concept through to completion.	https://www.irricad.com/
WEAP	WEAP (Water Evaluation And Planning system) is a concept-based model that takes an integrated approach to water resources planning	https://www.weap21.org/
REWAS	The REWAS (REal WAter Savings) tool is developed to undertake a quick impact assessment of field-scale experiments (either by models or pilot plots) on basin-scale potential water savings	https://www.futurewater.nl/wp-content/uploads/2020/06/FAO_REWAS_v08.pdf

Source: Authors' own elaboration.

TABLE 2
Assessment of existing tools for evaluating water flows in irrigation systems according to key criteria

Tool	Scale: field	Scale: irrigation system	Scale: basin	Focus: irrigation	Complexity	Use: practitioners	Use: training	Use: awarness
CROPWAT	5	2	1	5	2	3	3	3
AquaCrop	5	2	1	5	4	2	3	4
NaanCAT	3	5	3	5	4	4	3	1
IrriRT / IrriWorks	3	5	3	5	5	4	3	1
Wasim	5	2	1	3	4	3	2	2
SWAP	5	2	1	3	4	2	2	2
IrriCad	3	5	3	5	5	4	3	1
WEAP	3	3	5	3	3	2	4	3
REWAS	5	4	3	5	1	4	5	5
Follow the Water (FtW)	**3**	**5**	**4**	**5**	**1**	**4**	**5**	**5**

Note: Key criteria are those defined above in Section 2.3. Higher numbers are better, except for complexity where a lower value is deemed preferable.

Source: Authors' own elaboration.

2.4. Follow the Water tool

The Follow the Water (FtW) tool was developed to help understand water flows in irrigation systems. FtW is designed to follow flows and reuse of water in a simple and understandable manner. The tool is therefore primarily to be used in training, education and in the initial design of irrigation systems or their modernization.

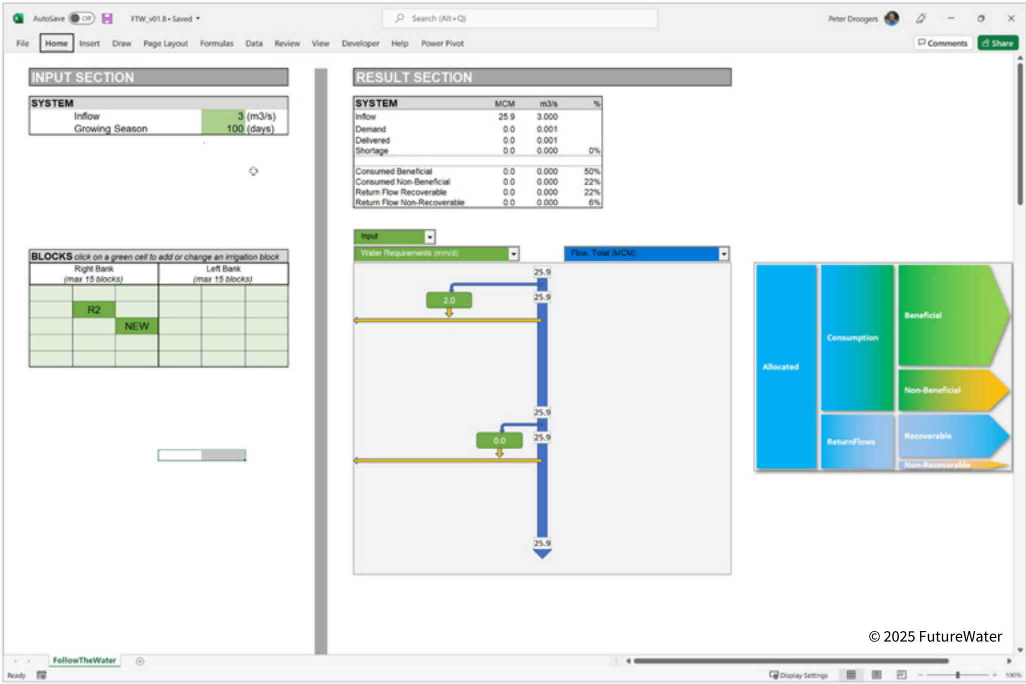
The basic concept of the tool is that an irrigation system has four main components:

- A main canal
- Secondary canals
- Drains
- Irrigation blocks (10 ha to 10 000 ha).

The second concept of FtW is the REWAS approach. REWAS (Real Water Savings in Agricultural Systems) was developed to include the missing link between point data (originating from research plots or AquaCrop) and system performance.

The third concept of the FtW tool is the use of virtual tracers, which is an innovative approach to track different sources and reuse of water. In the FtW tool, user-specific virtual tracers are added to drainage water to evaluate the mixing of return flows from each water user in sources of water supply to subsequent users (Simons *et al.*, 2020). Tracers have been known for decades and used by hydrologists by injecting artificial dyes into streams to determine flow rate and movement. Harmless dyes can be tracked from the point of injection to the point of recovery, which may be kilometres downstream. Tracers can be therefore used to track sources of water (for example glacial melt, snow melt, rainfall runoff) as well as to follow reuse of water. In the FtW tool a virtual tracer is added at a concentration of 1 gram to each litre of return flow. Complete mixing is assumed. In this way, tracer concentrations can be used to recalculate the percentage attributed to each return flow across the system under study.

FIGURE 11
Screenshot of the Follow the Water tool to explore interactions between irrigation blocks with a focus on return flows under various irrigation types



A more in-depth description of the FtW tool can be found elsewhere (Follow the Water – Manual), including practical guidance on using the tool as well as exercises and case studies. Figure 11 illustrates how the FtW tool can be used to explore the relationship between water flows and irrigation types.

The differences and complementarity between the REWAS and the FtW tool are their spatial domains of interest. REWAS is meant to evaluate field-scale interventions and their potential for real water savings at larger scales. FtW excels in analysing different irrigation methods (for example border, furrow, sprinkler, drip) within an irrigation system, using irrigation blocks (10 ha to 10 000 ha) as a base. Both tools were developed to be used for quick initial analysis of the impacts of interventions and to improve relevant professional's awareness and training.

In summary, the REWAS tool validates whether field water savings are real water savings. The Follow the Water tool aims at understanding the pathway of return flows and the site and extent of reuse.

3. Return flow quantification

3.1 Return flow database

Knowledge of typical volumes of water reuse in irrigation systems is a first step to account for water reuse in systems where such quantitative information is not yet available. A review of the literature on return flows was performed and a database of relevant studies was compiled. The following starting points guided the composition of this database:

- Initially, the literature review focused on papers and reports which explicitly reported volumes or percentages of recoverable return flows. However, because of the limited amount of identified studies that fit this requirement, the definition was broadened to include studies that set out to quantify irrigation return flows (that is which do not distinguish between recoverable or non-recoverable flows or analyse reuse).
- The focus was particularly on studies in Asia.
- All values in the database are valid for average annual conditions (unless otherwise specified). Interannual variability of return flows and reuse can be significant (Simons *et al.*, 2020).

Table 3 lists the properties that are included in the database for each estimate of water reuse and return flow. Single studies can report many such estimates, which are reported separately in the database.

TABLE 3

Information included in the database of water reuse literature

Header	Explanation
ID	Unique ID code
Country	Three spatial levels of information on location
Region	
Area	
Climate	Description of dominant climate zone
Area size (ha)	Irrigated surface area
Size category	Categorization of irrigated surface area (1) < 100 ha, (2) 100 ha to 1 000 ha, (3) 1 000 ha to 5 000 ha, (4) > 5 000 ha
Dominant crop	Dominant crop type
Irrigation type	Dominant irrigation type
Return flow fraction (RFF) (%)	Percentage of irrigation supply that returns to the hydrological system
RFF (%) accounts for reuse within spatial domain?	Flag indicating whether the estimated return flow in % accounts for internal reuse ("Y", indicating scale-dependency) or not ("N", representing the inverse of classical efficiency)
Surface or groundwater	Return flow and reuse estimates include surface water and interflow (SW), groundwater (GW), or both (SW, GW)
Recovered (%)	Percentage of return flow from the irrigated area that is actually reused downstream
Assessment method	Primary methods used in obtaining return flow and reuse estimates
Comments	Additional information
Source	Citation details

Source: Authors' own elaboration.

It is important to note that the return flow fraction can only be assumed to be related to scale, in cases where it accounts for reuse within the spatial domain of interest. Only then, an increased consumed fraction as a result of reuse can be expected. For studies that have not taken this into consideration, the return flow fraction is more or less the inverse of the classical irrigation efficiency[5] depending on the definition used of the latter.

3.2. Analysis

The total number of studies that reported clearly defined return flows is surprisingly very low. The final database contains about 50 quantifications of return flow numbers. The annex to this report presents an annotated bibliography, which describes selected studies from the literature review that are very precise in using correct definitions.

Similar inventories have created more extensive databases when they were less restrictive in their definitions. Two typical recent examples of such meta-analysis are also included in Perez-Blanco, Hrast-Essenfeld and Perry (2020) and Opstal *et al*. (2021).

The most challenging and complicated factor on obtaining useful data on return flows is the absence of a clear definition of what return flow refers to. In fact in nearly all publications this is so. The two main obstacles are:

- It is unclear whether the numbers presented relate to internal return flows or external return flows (see Figure 8 "reuse within spatial domain").
- Related to the previous point: the spatial domain of interest of the data presented is often not specified.

The implications of the spatial domain can be easily understood in two contrasting examples. When considering the spatial domain of the entire world, the internal return flow is 100 percent and the external one is 0 percent; no water flows out of the world. In contrast, assuming a very small spatial domain, for example a drop of water or a few mm^2 of land. All water on that mm^2 of land is probably not used at that specific point and all water flows to the nearest plant root. So, for that particular mm^2 of land the internal return flow is 0 percent and the external return flow is 100 percent; all water flows out of that mm^2 of land.

In practice the spatial domain of interest is in many cases a field, an irrigation block (secondary canal, or tertiary canal), or an entire irrigation system.

Table 4 shows the number of studies or reports found where return flows were quantified and documented. That the total number of studies was low indicates that return flow quantification is not a high priority. The majority of studies on irrigation water flows is still very much focused on changes of water allocation or supply under various scenarios, rather than on a complete Follow the Water approach.

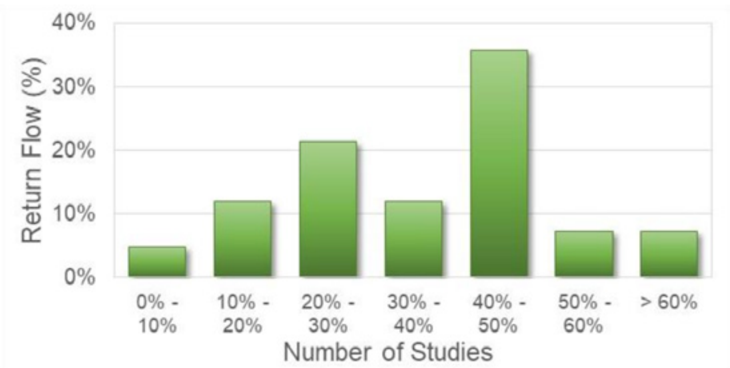
5 Irrigation efficiency is used extensively, but the definitions applied vary widely, for example "the ratio of the amount of water available (output) to the amount of water supplied (input)" from Brouwer *et al*. (1989), or "the net amount of water added to the root zone divided by the amount of water taken from some source" from Hillel (2008), or "the ratio between irrigation water actually utilized by growing crops and water diverted from a source (as a stream)" in Merriam-Webster.com.

TABLE 4
Number of studies found that quantified return flows according to the defined criteria

Country	Number of studies
Bangladesh	1
China	9
France	1
India	8
Iran (Islamic Republic of)	2
Japan	2
Republic of Korea	1
Pakistan	1
Spain	1
Taiwan Province of China	6
Türkiye	1
Viet Nam	9
United States of America	3
Total	**45**

Source: Author's own elaboration.

FIGURE 12
Return flow values based on the literature review



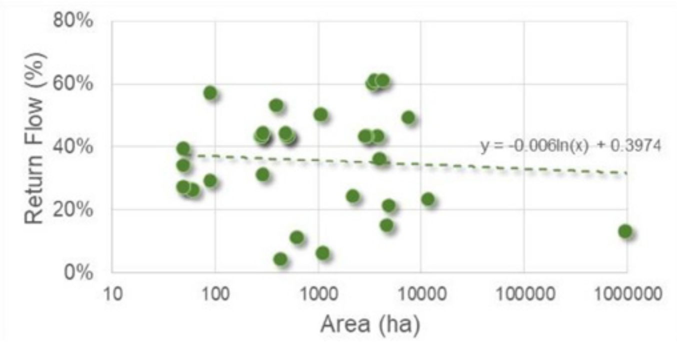
Source: Authors' own elaboration.

The average return flow value obtained from the literature search was 35 percent, with a large variation. Figure 12 indicates that about 50 percent of the studies reported return flows between 30 percent and 50 percent. The two studies that reported return flows lower than 10 percent excluded deep percolation from their analyses and did not report how big those percolation flows were.

As indicated earlier, it can be expected that external return flows, defined as the flows flowing out of the spatial domain of interest, are a function of area size (spatial domain of interest). In Figure 13 all the individual data points were plotted for which the area of the spatial domain of interest was reported. The expected trend that with the larger areas the external return flows would be smaller (since the internal return flows are bigger) is visible in Figure 13. It should be noted however that this trend is by and large influenced by the return flow number of 13 percent with an area of about 1 million hectares (Zhangye Basin in Northern China). Other large-scale river systems might have similar numbers for external return flow. A rough estimate of return flow based on data from the entire Indus Basin shows that total inflow (so including all source catchments) is about 175 BCM and outflow is about 35 BCM (Hussain *et al.*, 2011), so the return flow is 20 percent.

FIGURE 13

Scatter plot of return flow versus area of consideration (log scale)



Source: Authors' own elaboration.

For the Colorado River in the United States of America, annual water account reports are published (Bureau of Reclamation, 2022). Data presented in those reports make a clear distinction between diversions, consumption and returns. Annual return flows reported are high and range between 14 percent and 50 percent for the year (Table 5). However, the reported return flows are based on the sum of the individual return flows within the three states (in fact the situation as shown in Schematic A of Figure 8). Table 6 presents as an example the separate diversions and associated return flows for California for 2021. These return flow fractions range between 7 percent and 54 percent. Again, within each of these separate diversions, most likely a complex reuse system is present.

TABLE 5

Number of studies found that quantified return flows according to the defined criteria

	Arizona	California	Nevada
Diversion (MCM/y)	3 986	6 156	593
Return flows (MCM/y)	994	887	295
Consumption (MCM/y)	2 992	5 433	299
Return flows (%)	25%	14%	50%

Source: Adapted from Bureau of Reclamation. 2022. *Colorado River accounting and water use report: Arizona, California, and Nevada: calendar year 2021.* United States Department of the Interior, Bureau of Reclamation. https://crb.ca.gov/wp-content/uploads/2023/01/20230111-board-folder.pdf

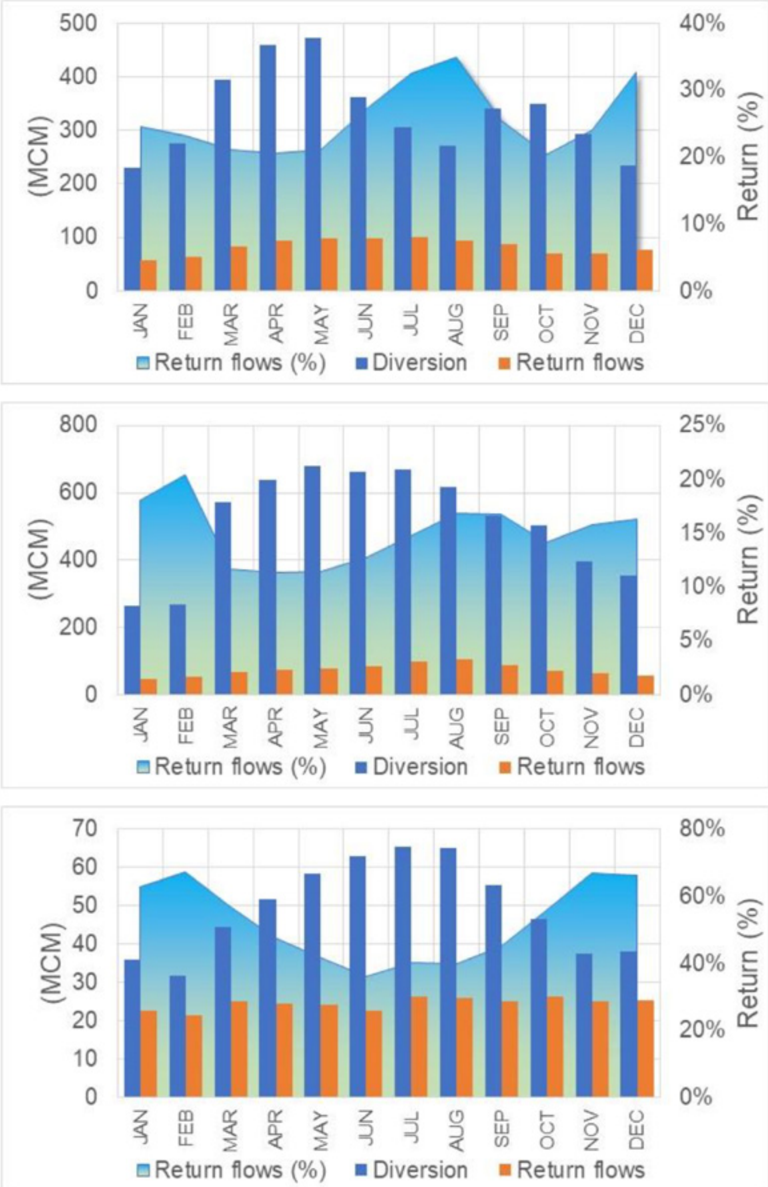
TABLE 6

Water diversions, return flows, consumed and return flow fractions for the Colorado River in California in 2021

	Diversion (MCM/y)	**Return Flows** (MCM/y)	**Consumed** (MCM/y)	**Return Flow Fraction** (%)
Fort Mojave Indian Reservation	16	7	9	46%
City of Needles	2	1	1	41%
The Metropolitan Water District of Southern California	1 330	3	1 327	0%
Palo Verde Irrigation District	1 000	545	455	54%
Yuma Project Reservation Division	97	51	46	52%
Fort Yuma Indian Reservation	5	2	3	45%
Yuma Island California	4	2	2	45%
Imperial Irrigation District	3 229	239	2 990	7%
Coachella Valley Water District	470	36	434	8%
Others	3	1	2	40%
TOTAL	**6 156**	**887**	**5 269**	**14%**

Source: Adapted from Bureau of Reclamation. 2022. *Colorado River accounting and water use report: Arizona, California, and Nevada: calendar year 2021.* United States Department of the Interior, Bureau of Reclamation. https://crb.ca.gov/wp-content/uploads/2023/01/20230111-board-folder.pdf

FIGURE 14
Colorado river water accounts for 2021



Source: Adapted from Bureau of Reclamation. 2022. *Colorado River accounting and water use report: Arizona, California, and Nevada: calendar year 2021.* United States Department of the Interior, Bureau of Reclamation. https://crb.ca.gov/wp-content/uploads/2023/01/20230111-board-folder.pdf

Note: Top: Arizona; middle: California; bottom: Nevada. Scales are different for the three graphs.

Finally, monthly variation of return flows is quite high as shown in Figure 14. The general trend seems to be that with higher diversions return flow fractions are lower. This might be explained by the fact that during periods with higher demands more water is actually consumed by users

A factor hardly covered in any of the studies found is the differentiation of return flows between recoverable and non-recoverable. This distinction is highly relevant as policy and management implications are relevant to this. There is not much gain in reducing recoverable return flows, as those can be potentially used by other (downstream) users, whereas non-recoverable return flows can be considered as real losses of precious water.

Finally, none of the studies made it explicitly clear whether any of the documented recoverable return flows were actually recovered (reused) by downstream users. Again, this is very relevant for policy and management implications. In cases where the return flows were recovered specific policy and management measures are in fact not needed. In cases where the recoverable return flows are not used, one could either try to reduce those flows, or develop downstream options to reuse them. Obviously, established water use and perhaps water rights should be always considered and respected.

Recently, a related study on the impact of advanced irrigation methods on water conservation (Perez-Blanco, Hrast-Essenfekder and Perry, 2020) presented an extensive review of the theoretical and empirical literature to assess whether higher physical irrigation efficiencies achieved through water conservation technologies actually conserve water. Most of these technologies were improved irrigation technologies, for example changes from border or furrow irrigation to sprinkler or drip systems. A total of 230 studies was found to be relevant and included in the database.

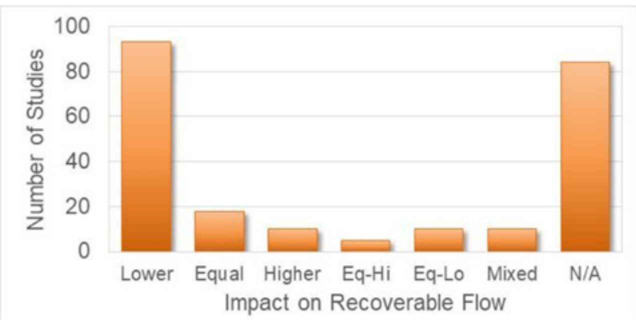
Interestingly, of those 230 studies, less than one third reported the impact of changes in irrigation systems on return flows (Figure 15). Of the remaining 146 studies, 93 (64 percent) reported that return flows decreased after modernization. Less than 7 percent of the studies for which return flows were reported, showed an increase in return flows after modernization of irrigation technology. The conclusion of this literature study indicates clearly that changing irrigation methods to more modern ones (pressurized systems) leads in nearly all cases to a decrease in return flows. The study also concluded that farmers that implemented advanced irrigation systems would in most cases obtain a higher income from either higher yields or increased cropped area.

Of 21 interventions found in the literature review, the actual values of those changes in return flows were reported (Figure 16). In only 2 out of those 21, a small increase in return flows was found (9 percent and 4 percent). For the remaining cases, it was reported that the return flows reduced on average by 27 percent, ranging from a few percentage points to 82 percent.

From a policy and management perspective, it is clear that water savings and conservation technologies can often lead to a decrease in return flows and an increase in consumption, and should therefore be considered in each decision process. Decision-makers and water managers should therefore think about water entitlements and allocations to individual farmers. The Follow the Water approach can be instrumental in supporting decision-makers in these aspects.

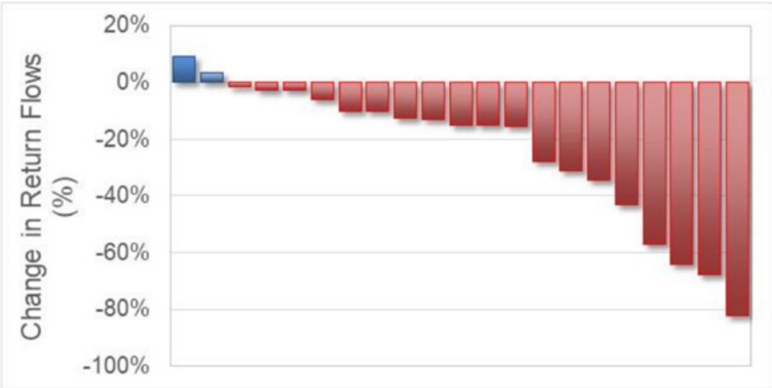
FIGURE 15

Impact of conservation technologies (mainly more advanced irrigation application technologies) on recoverable flows



Source: Based on renanalysis of data from Perez-Blanco, C.D., Hrast-Essenfelder, A., & Perry, C. 2020. Irrigation technology and water conservation: a review of the theory and evidence. Rev. Environ. Econ. Policy 14, 216–239. [online]. [Cited 11 February 2022]. https://doi.org/10.1093/REEP/REAA004

FIGURE 16
Impact of conservation technologies (mainly more advanced irrigation application technologies) on return flows



Source: Based on reanalysis of data from Perez-Blanco, C.D., Hrast-Essenfelder, A., & Perry, C. 2020. Irrigation technology and water conservation: a review of the theory and evidence. Rev. Environ. Econ. Policy 14, 216–239. [online]. [Cited 11 February 2022]. https://doi.org/10.1093/REEP/REAA004

TABLE 7
Percentages of field intervention studies (mainly water "savings" technologies) that reported an increase or a decrease in a certain process

Irrigation Increase **Irrigation Decrease**	1% 48%
Evapotranspiration Increase **Evapotranspiration Decrease**	12% 28%
Yield Increase **Yield Decrease**	46% 18%
Water Productivity Increase **Water Productivity Decrease**	17% 5%

Note: The sum of each component is not 100 percent as not all information was provided in the studies.) Results are based on 240 interventions.

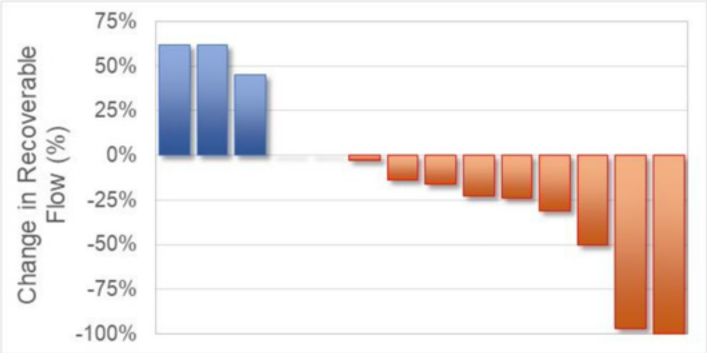
Source: Adapted from Van Opstal, J., Droogers, P., Kaune, A., Steduto, P. and Perry, C. 2021. *Guidance on realizing real water savings with crop water productivity interventions*. FAO Water Reports 46. Wageningen, FAO and FutureWater. https://doi.org/10.4060/cb3844en

A third literature review was completed in 2021 looking at real water savings in agricultural systems (REWAS) (Opstal *et al*., 2021). The focus of the review was studies on water savings technologies at field-scale level and their impacts on water balances, water productivity and recoverable flows. A total of 240 experiments was included in the review.

Although the review was focused on field-scale interventions, some information documented is relevant for return flows. Table 7 summarizes the main findings on the impact of field interventions, mainly to more advanced irrigation and agronomic methods, on irrigation, evapotranspiration, yield, and water productivity.

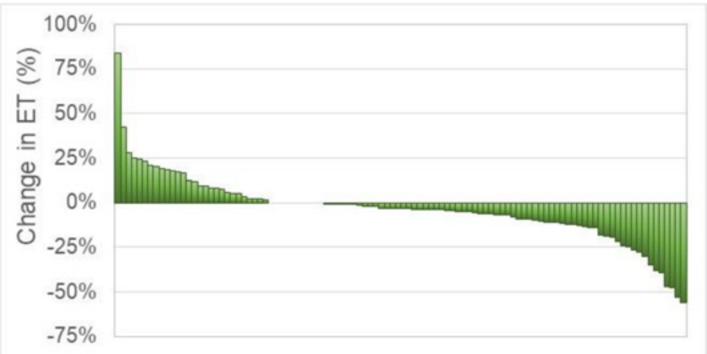
Figure 17 shows the changes in return flows according to the literature review. Interestingly, only 14 out of the 240 studies made reference to return flows, also indicating that these flows were not always conceived as important. For the studies that reported return flows, numbers range from an increase by 60 percent to a decrease of as much as 100 percent. Again, from a management and policy perspective this is highly relevant as most likely the downstream users who depended on return flows would be highly impacted if the proposed interventions were to be implemented at scale.

FIGURE 17
Impact of field interventions (mainly watersavings technologies) on changes in recoverable flows



Source: Based on re-analysis of data from Van Opstal, J., Droogers, P., Kaune, A., Steduto, P. and Perry, C. 2021. Guidance on realizing real water savings with crop water productivity interventions. FAO Water Reports 46. Wageningen, FAO and FutureWater. https://doi.org/10.4060/cb3844en

FIGURE 18
Impact of field interventions (mainly water savings technologies) on changes in growing season actual evapotranspiration (ET)



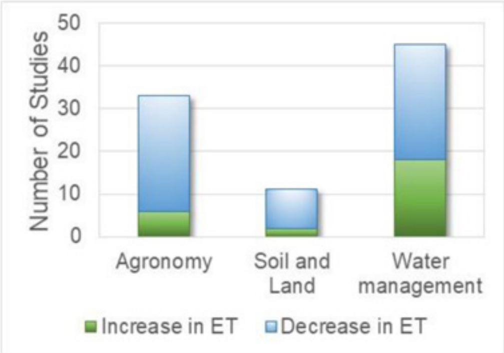
Note: Of the 240 interventions in the database, 104 reported ET.

Source: Based on re-analysis of data from Van Opstal, J., Droogers, P., Kaune, A., Steduto, P. and Perry, C. 2021. *Guidance on realizing real water savings with crop water productivity interventions.* FAO Water Reports 46. Wageningen, FAO and FutureWater. https://doi.org/10.4060/cb3844en

The impact of irrigation application technologies and actual evapotranspiration rates were quantified in many of the studies found in the literature review. Figure 18 shows that higher consumption (even up to 80 percent) can be expected for many interventions. Obviously, this will have a big impact on the expected return flows.

The database included a classification of the type of intervention: (i) agronomy; (ii) soil and land; or (iii) water management. Apparently, most of the agronomy interventions and the soil and land interventions even have the tendency to decrease evapotranspiration. For the water management interventions, nearly 40 percent will lead to an increase in actual evapotranspiration (Figure 19). Importantly, all interventions in the database are field based and interventions that encompass water allocation reductions are not included in the inventory.

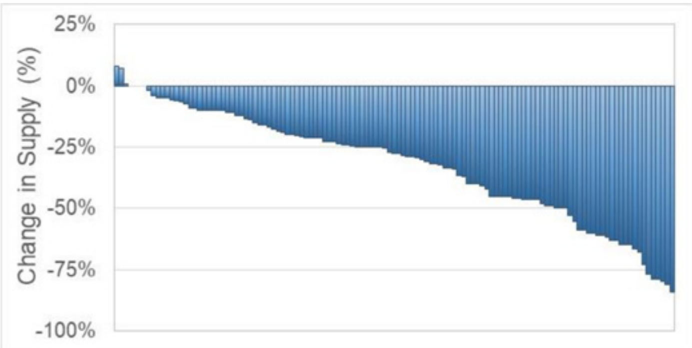
FIGURE 19
Impact of field interventions (mainly water savings technologies) on changes in actual evapotranspiration (ET)



Based on re-analysis of data from Van Opstal, J., Droogers, P., Kaune, A., Steduto, P. and Perry, C. 2021. *Guidance on realizing real water savings with crop water productivity interventions.* FAO Water Reports 46. Wageningen, FAO and FutureWater. https://doi.org/10.4060/cb3844en

Finally, Figure 20 shows that in almost all interventions the irrigation application was reduced. A reduction in irrigation application is not the same as saving water since these reduced applications might lead in many cases to a reduction in return flows, which is not the same as water savings. Moreover, the studies that were reported are often undertaken in a research mode on experimental fields. As mentioned earlier, in many cases it would be questionable whether farmers will accept a reduction in water supply after investing in a certain intervention.

FIGURE 20
Impact of field interventions (mainly water savings technologies) on changes in water supply by irrigation



Note: Of the 240 interventions in the database, 121 reported these numbers

Source: Authors' own elaboration.

4. Conclusions and way forward

The main conclusion from this study is that knowledge, information, and data on reuse of water in irrigated agriculture is poor. The main reason is the narrow-minded focus on changes in irrigation applications only, rather than a Follow the Water approach. This has resulted in a lack of proper analysis of tracking water flows in irrigated systems and finding real water savings opportunities. Decades of education and training of irrigation experts on efficiencies have contributed to this rather limited evaluation of water challenges and has hampered the implementation of effective solutions. This is in contrast to hydrologists, whose education and training have exposed them to the idea that a closed water balance is a fundamental feature of hydrological systems.

This lack of tracking water flows has led to unwise investments in the irrigation sector. Projected water savings have often not been realized, leaving farmers and potentially other users in limbo. The databases developed and evaluated in this study emphasized the lack of proper analysis in research and decision-making in the irrigation sector. In cases where Follow the Water principles were used, the overall conclusion is that changes to more advanced irrigation technologies will increase water consumption and reduce return flows. The increases in water consumption will be to the advantage of farmers concerned (more crop produced) whereas the reduction in return flows will be to the disadvantage of potential downstream users.

The study attempted to quantify reuse rates in irrigated agricultural systems. Based on the extensive literature review no specific numbers could be given. In general, return flows are in the order of 30 percent to 50 percent at irrigation block level. Correlations with biophysical conditions, such as climate, soils, and crops, could not be found because of a lack of sufficient data. A correlation, although weak, between reuse rates and spatial domain of interest has been detected: larger areas tend to have lower recoverable flows. This is mainly because the internal reuse of a system increases with its area.

The Follow the Water tool as introduced in this study can be used to undertake a quick initial analysis of impacts of interventions and as an awareness-raising and training instrument. It has already successfully been applied in Thailand, Viet Nam, Cambodia, Indonesia, Lao People's Democratic Republic and Indonesia where technical experts representing government authorities responsible for water resources management at the national, local, and basin levels received training on the Follow the Water and REWAS approaches under the Asia-Pacific Water Scarcity Programme (WSP) developed by the FAO Regional Office for Asia and the Pacific. The main recommendation from the current analysis is clear: every study or intervention on proposed changes in irrigation technologies should be based on the Follow the Water approach.

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5. Annex: Annotated bibliography

This section summarizes the scope and key results from the few studies that can be considered as among the most informative in terms of using the Follow the Water approach.

Chinh, L. Van. 2012. *Return flow and reuse of drainage water in a rice-based irrigation and drainage area in the Red River Basin, Vietnam: a study on the quantification and assessment of return flow and drainage reuse for the integration of irrigation and drainage management.* University of Copenhagen, Faculty of Science, Department of Basic Sciences and Environment. (PhD dissertation).

The primary goal of this study was to develop and apply an integrated water balance framework to quantify the return flow and to assess the importance of the drainage reuse system in a rice-based irrigation and drainage area (Cau Son irrigation and drainage system in Red River Basin, Viet Nam) at farm, scheme and catchment levels. A conceptual framework of the reuse system was developed and reuse indicators were defined to characterize drainage reuse systems. An integrated water balance model was built and solved to identify and quantify the return flow from the Cau Son canal irrigation scheme. It was found that Cau Son canal irrigation scheme was a significant source of drainage water and water level variation in the main drain. Quantitative estimates of potential and actual reuse ratios, as well as the dependency of reuse schemes on return flow from the canal scheme, were computed for different spatial scales.

Mohan, S., & Vijayalakshmi, D. P. 2009. Prediction of irrigation return flows through a hierarchical modeling approach. *Agricultural Water Management*, 96(2): (233–246).

The estimation of return flow from an irrigation system is usually obtained using rules of thumb depending upon the site-specific conditions such as command area conditions and soil properties. In this paper, a hierarchical modeling technique, namely regression tree, is developed for return flow estimation. Regression tree is built through binary recursive partitioning. The effective rainfall, inflow, consumptive water demand, and percolation loss are taken as predictor variables and return flow is treated as the target variable. The applicability of the hierarchical model is demonstrated through a case study of the Periyar-Vaigai Irrigation System in Tamil Nadu, India. The model performance shows a good match between the simulated and the field measured return flow values. Results of statistical analysis indicated that the correlation coefficients are high for both single as well as double crop seasons.

Wu, D., Cui, Y., Wang, Y., Chen, M., Luo, Y., & Zhang, L. 2019. Reuse of return flows and its scale effect in irrigation systems based on modified SWAT model. *Agricultural Water Management, 213, 280–288.*

Return flows in irrigation systems are often reused contributing to overall efficiency. To investigate the fate of return flows and the scale effects of reuses, the Soil and Water Assessment Tool (SWAT) model was modified to better represent the characteristics of paddy rice irrigation systems, which includes a simulation module for automatic multi-source irrigation (AMSIM). The modified SWAT model was used to simulate the hydrological processes in the Yangshudang (YSD) watershed of the Zhanghe Irrigation System (ZIS) in China. Furthermore, a method to calculate the amounts of return flows and the reused amount based on the output of the model was proposed. The sub-basins nesting method was used to divide the study area into six scales. The rainfall and irrigation water reuse rates (ηI+P) and the irrigation water reuse rates (ηI) were calculated at different scales and the changes in these two indicators over different scales were analyzed. It was revealed that the modified SWAT model succeeded in simulating hydrological processes in a paddy rice irrigation system. The results were that $\eta I+P$ and ηI increased with the increase of scale. Moreover, $\eta I+P$ was higher in the wet years and lower in the dry years, whereas ηI was higher in the dry years and lower in the wet years. The reason for increase of $\eta I+P$ and ηI as the scales increases was the fact that the return flows were repeatedly intercepted by downstream paddy fields, farm ponds, and drainage channels at larger scales, These reuse rates however reach the upper limit at a scale of 3 500 ha, after which $\eta I+P$ and ηI no longer increase.

Koech, R., & Langat, P. 2018. Improving irrigation water use efficiency: a review of advances, challenges and opportunities in the Australian context. Water 10(12): 1771 [online]. [Cited 12 February 2022]. https://doi.org/10.3390/w10121771

This paper reviewed the advances made towards improving irrigation water use efficiency (WUE), with a focus on irrigation in Australia. Some examples from other countries were also included. The review showed that improvements in irrigation infrastructure through modernization and automation have led to water savings.

The review has demonstrated that the adoption of water-efficient technologies has delivered water savings at the field scale, with some of the savings being released as environmental flows. However, the net water saving at the basin scale is not always achievable. In fact, some studies have demonstrated that a net increase in water consumption, largely as a result of the reuse of the saved water, have expanded the area of land under irrigation. Hence, an overall reduction of water consumption at the basin scale is likely to be achieved when water-efficient technologies are used in combination with other measures, such as provision of incentives for water conservation and regulations to limit water allocation.

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