Food and Agriculture Organization of the United Nations

# Follow the Water

Manual

FutureWater

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Peter Droogers, Gijs Simons, Jonna van Opstal and Johannes Hunink
FutureWater, Wageningen, the Kingdom of the Netherlands

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# 1. Introduction

## 1.1 Relevance

Agriculture demands and consumes more water than any other economic sector and globally is responsible for more than 85 percent of all human-induced water withdrawals (D'Odorico *et al.*, 2020). An increase in water use over the last 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 (Intergovernmental Panel on Climate Change, 2019) and climate change (Turral, Burke and Faures, 2011). As irrigation is the largest consumer of freshwater withdrawals in almost all water-scarce regions, it appears that solutions to reverse this trend should focus on irrigated agriculture.

Options to save water therefore have tended to focus on irrigation, specifically, improved irrigation technologies (such as drip irrigation, sprinkler, pressurized systems), which are promoted as legitimate means of increasing water efficiency and saving water for other uses such as domestic use and the environment. However, a growing body of evidence, including a key report by FAO (Perry and Steduto, 2017), shows that in the vast majority of cases expected water savings by improved irrigation technologies are rarely realized and in most cases the introduction of improved irrigation technologies actually results in an increase in water consumption.[1] The Follow the Water (FtW) tool can be used to explain this unexpected outcome.

The Follow the Water (FtW) tool helps users to understand water flows in irrigation systems. It is designed to follow flows and the reuse of water in a simple and understandable manner. The tool is primarily aimed at users in education and training contexts, and in the initial design of irrigation systems.

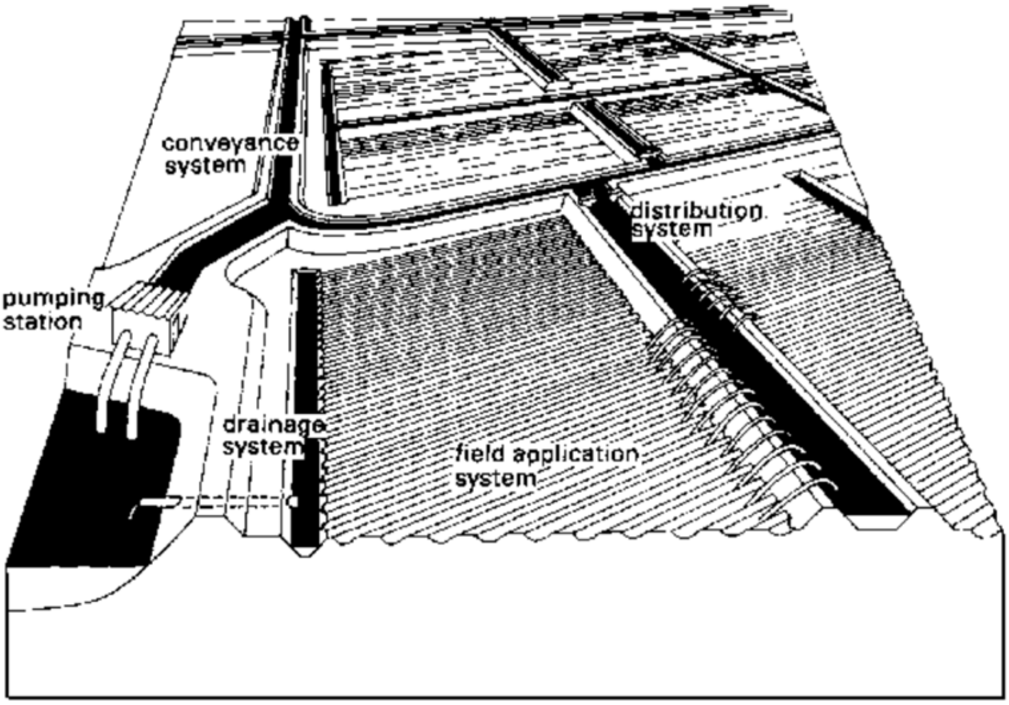
## 1.2 Overview of irrigation systems

The basic components of any irrigation systems are an intake structure, a conveyance system, a distribution system, a field application system, and a drainage system as shown in Figure 1.

- 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 and a pump must be used to supply water to the irrigation system.
- 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.

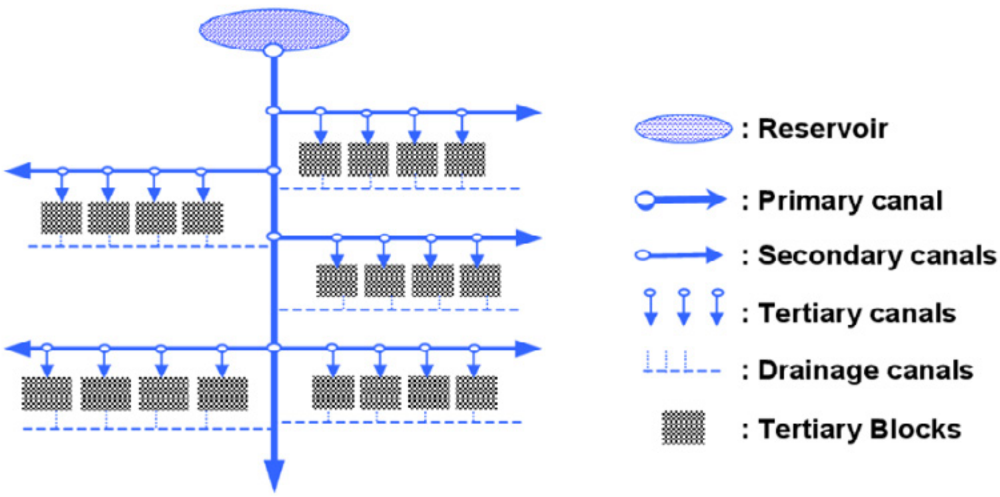
[1] A more detailed discussion can be found in the accompanying document Reuse of water in agricultural systems – Follow the Water.

FIGURE 1
**Classic drawing of an irrigation system**




Source: Brouwer, Goffeau and Heibloem (1985)

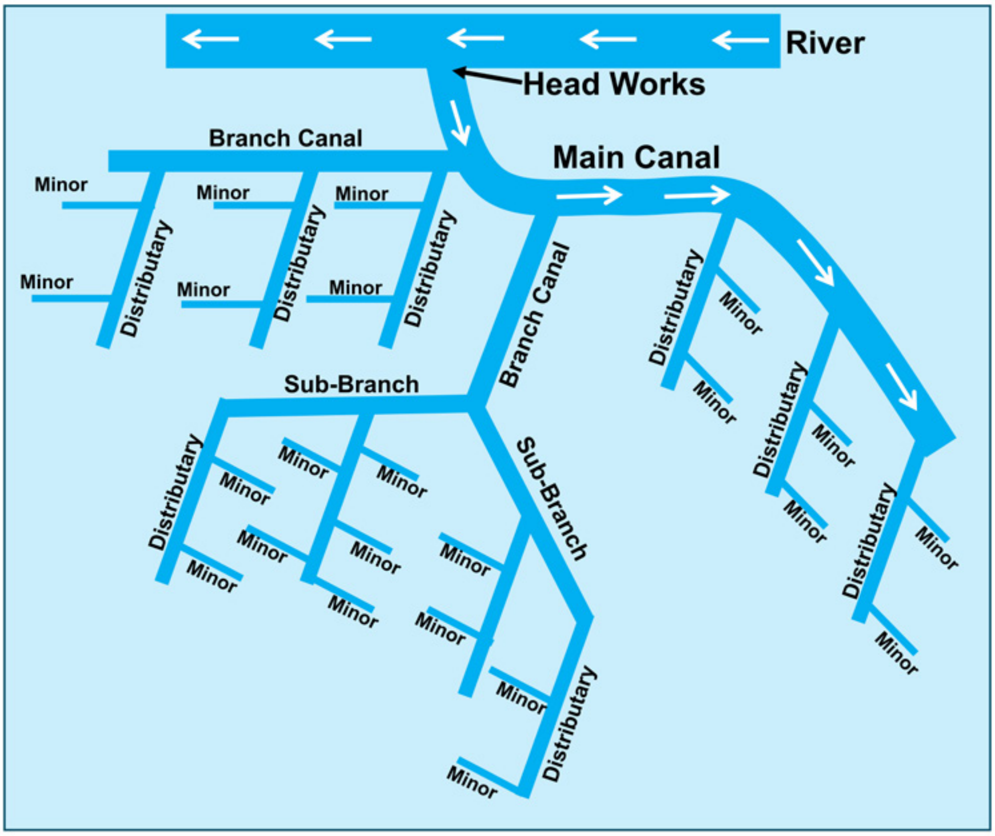
FIGURE 2
**General schematic layout of an irrigation system**




Source: Hellegers, P.J.G.J. 2006. The role of economics in irrigation water management. *Irrigation and Drainage*, 55(2): 157–163. https://doi.org/10.1002/ird.223

A general schematic layout of an irrigation system is shown in Figure 2 and a more detailed schematic is shown in Figure 3.

FIGURE 3
**Detailed schematic layout of an irrigation system**




Source: Adapted from Civil Planets (n.d.)

## 1.3 The Follow the Water Approach

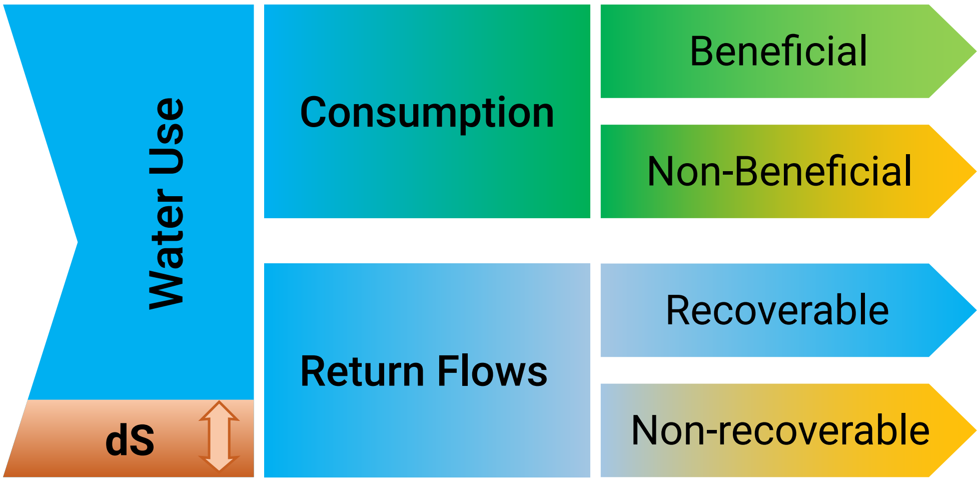
Incorporating water reuse in agricultural water management strategies and processes starts with the distinction between consumed and non-consumed flows. This report makes use of the concepts of the simplified Follow the Water (FtW) approach, which is based on the work of Perry (2011) and summarized by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

- The consumed fraction[2], comprises:
  - Beneficial consumption (for the purpose intended or another beneficial use); and
  - Non-beneficial consumption (such as by weeds, evaporation from wetted surfaces, or capillary rise during a fallow period).
- The return flow fraction, comprises:
  - Recoverable flows (water flowing to drains and back into the river system for possible diversion downstream, and percolation to freshwater aquifers); and
  - Non-recoverable flows (percolation to saline aquifers, outflow to drains that have no downstream diversions or direct outflow to the ocean).

Note that the term dS in Figure 4 refers to changes in storage in the system. Those can be negative (diversions > consumptions + return flows) or positive. Over longer time periods this usually is zero, unless unsustainable aquifer pumping is practiced.

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

FIGURE 4
**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

## 1.4 Follow the Water Tool

The Follow The Water (FtW) tools helps users to understand water flows in irrigation systems. 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 the FtW tool is the Real Water Savings in Agricultural Systems (REWAS) approach. REWAS was developed to include the missing link between point data (originating from research plots or AquaCrop[3]) and system performance.

The **third concept** of the FtW tool is the use of virtual tracers (see Box 1). A quite innovative approach to follow the source of water was incorporated using virtual tracers. Instead of using these tracers in reality, the FtW tool algorithms include virtual tracers. To each calculated return flow a tracer was added at a concentration of 1 gram per litre. Complete mixing was assumed with other freshwater supplies and other return flows. In this way, tracer concentrations can be used to recalculate the percentage of return flow in each part of the system under study.

[3] 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.

BOX 1
**Tracers**

Tracers have been used for decades. They are harmless dyes that are injected by hydrologists into streams to determine flow rate and movement. The tracers can be tracked from the point of injection to the point of recovery, which may be many kilometres downstream. In this way tracers can be used to track sources of water (for example, glacial melt, snow melt, rainfall runoff) as well as to follow the reuse of water when added to return flows in, for example, drains.

There are several types of hydrological tracers that can be used to characterize a watershed. Common tracers include dyes, salts, and stable isotopes. These tracers can be added to a waterbody to help to constrain residence time, or the time it takes for a molecule of water to flow from point A to point B, to characterize the inputs and outflows of water (where does the water come from and where does it go?), and to determine mixing and flow paths of water within a system (how it gets from point A to point B).

Typical applications of these tracers include:

- determining constraining residence time, or the time it takes for a molecule of water to move from point A to point B;
- characterizing how water moves within the watershed, including potential inputs (for example, precipitation versus groundwater) of water to a system and outflows (for example water lost to groundwater versus streamflow) of the water within the system; and
- determining mixing and flow paths of water within a system.

Source: Bruckner, M.Z. 2007. Using hydrological tracers to characterize a watershed. Microbial Life–Educational Resources. Montana State Universty, Bozeman. [online]. [Cited February 2023] https://serc.carleton.edu/17502

In summary, the intended use of the FtW tool is to detect the impacts of changes in irrigation systems' allocations, consumptions and return flows in a user-friendly Excel environment. The tool can therefore be used in training, education, and in the initial design of irrigation systems. For in-depth and detailed analyses, more advanced and complex software systems should be considered.

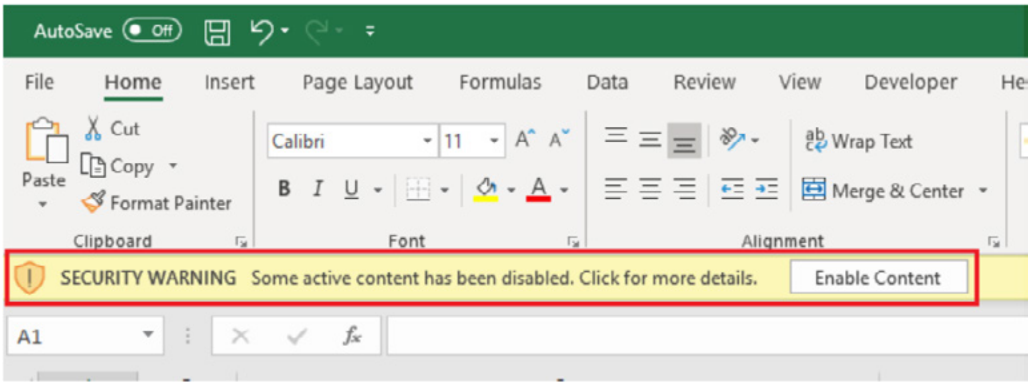
The current document is meant to be the starting point in using the FtW tool. The following chapters help the reader stepwise to become acquainted with the tool and be able to use FtW. More detailed discussions on the theoretical background and concepts can be found in the accompanying guidance document Reuse of water in agricultural systems – Follow the Water.

# 2. Introduction to the Follow the Water tool

## 2.1 Opening the Follow the Water tool

The Follow the Water (FtW) tool was developed in Excel and makes extensive use of macros[4], which are sequences of automated inputs that do the work of keystrokes or mouse actions. When opening FtW you will get a security warning that macros have been disabled (Figure 5). Click “Enable Content” to make sure FtW will work properly.

FIGURE 5
**Screen after opening Follow the Water tool**

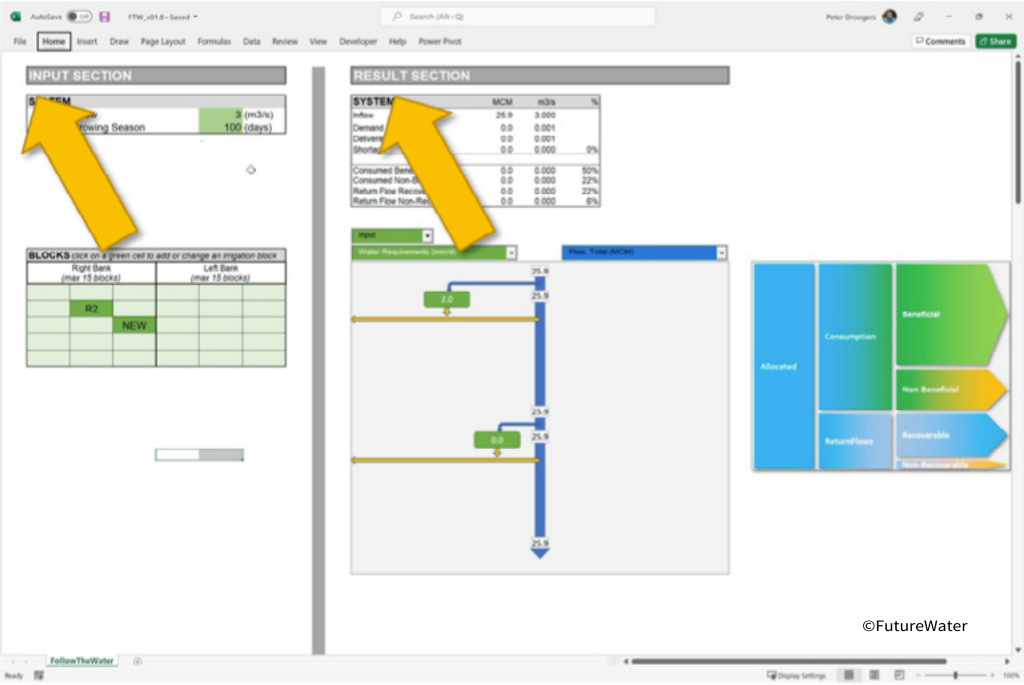



Source: Author's own elaboration.

[4] Given the extensive use of macros, the Follow the Water tool works only on Windows.

## 2.2 Input and result sections

FIGURE 6
**Overview of the input section and result section of the Follow the Water tool**



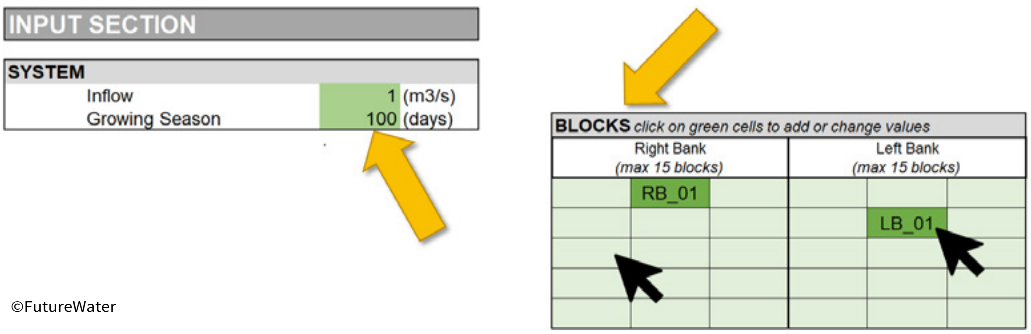

Source: Author's own elaboration.

The basics of the FtW tool are quite simple. There are two sections: one for INPUT and one for RESULT as shown in Figure 6.

The input section requires input at system level and at block level. Do remember that the FtW tool deals with one irrigation system and a maximum of 30 irrigation blocks. As mentioned before, a block should be considered as an area of multiple fields, having one supply and one return canal/drain. Blocks can be of any size ranging from a few hectares to thousands of hectares.

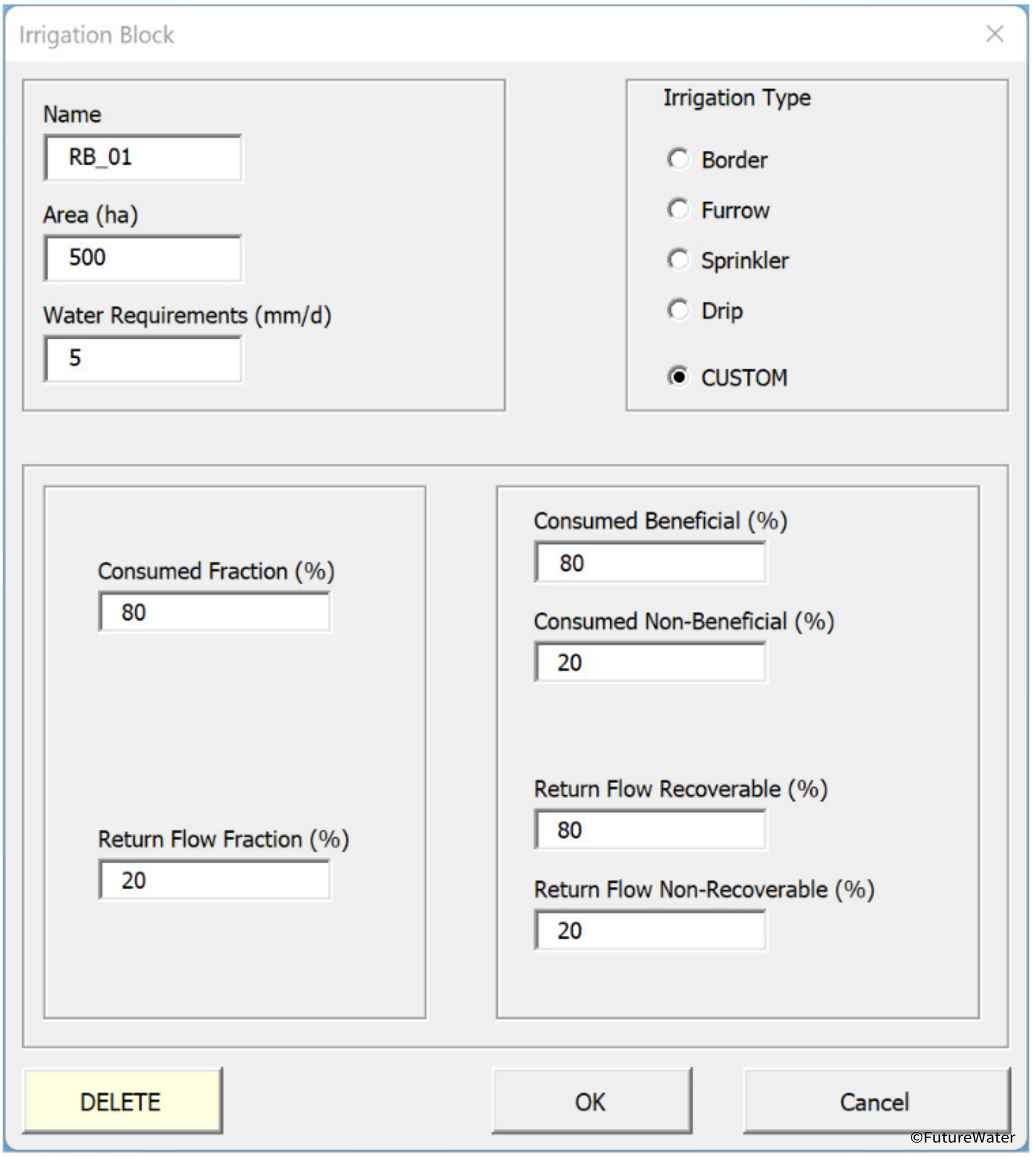
At the top, data at irrigation system level should be entered, at the bottom, data at irrigation block level should be provided. By clicking on a light green cell a new irrigation block can be added. By clicking on a dark green cell data of an existing irrigation block can be changed (Figure 7).

FIGURE 7
**Overview of the input section of the Follow the Water tool**




Source: Author's own elaboration.

FIGURE 8
**Input form for one irrigation block**

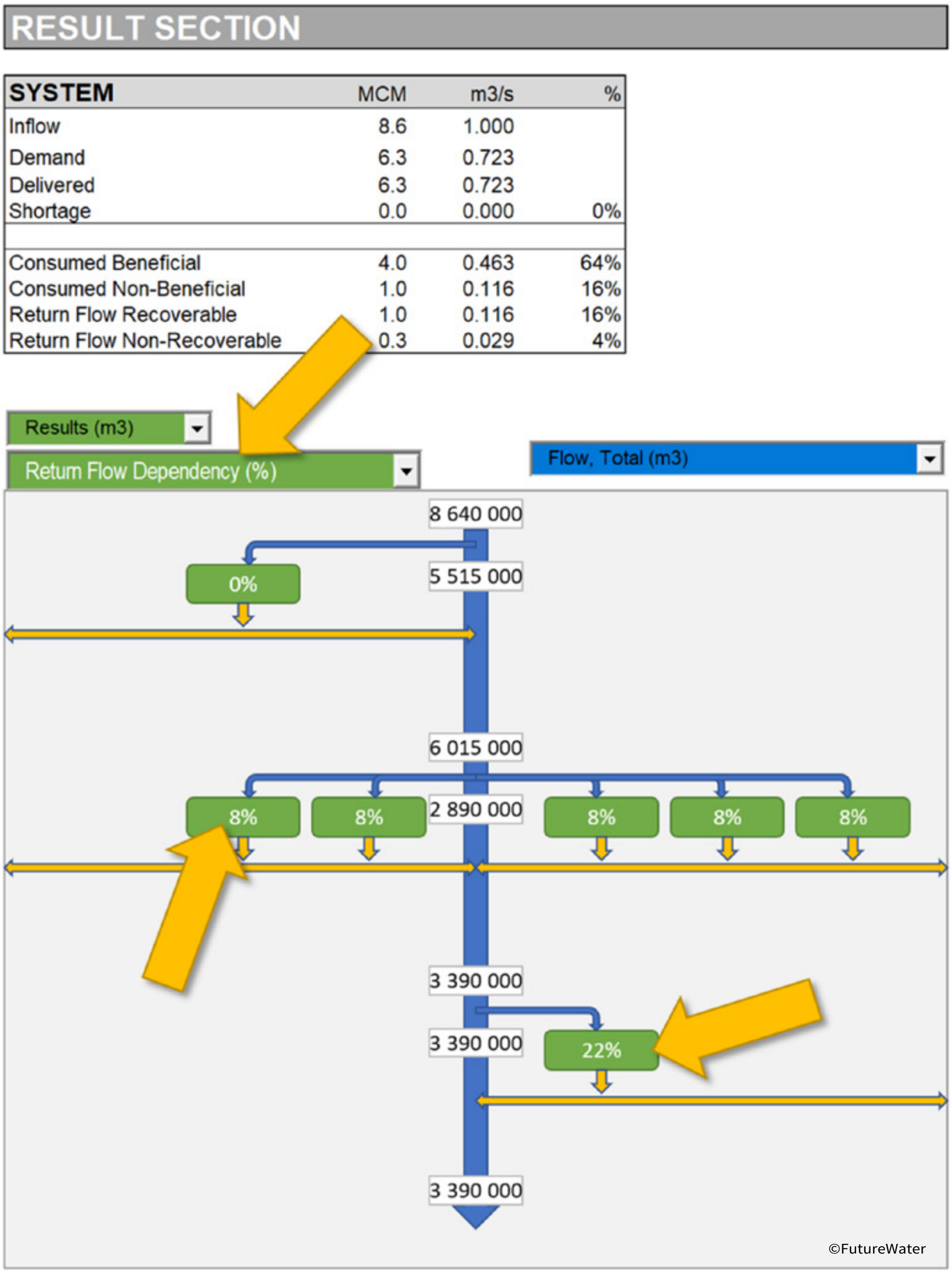



Source: Author's own elaboration.

By clicking on one of the irrigation blocks a form will pop up in which specific data for that particular block can be entered (Figure 8).

The result section will be automatically updated when changes in the input are made. The various drop-down menus shown in Figure 9 can be used to change the numbers in the graphical results. Note that the green drop-down menus will change the results of the blocks whereas the blue drop-down menus are used to show different flow components in the main canal (Figure 9).

FIGURE 9
**Example of output displaying the return flow dependency of irrigation blocks**



| SYSTEM | MCM | m3/s | % |
|---|---|---|---|
| Inflow | 8.6 | 1.000 | |
| Demand | 6.3 | 0.723 | |
| Delivered | 6.3 | 0.723 | |
| Shortage | 0.0 | 0.000 | 0% |
| Consumed Beneficial | 4.0 | 0.463 | 64% |
| Consumed Non-Beneficial | 1.0 | 0.116 | 16% |
| Return Flow Recoverable | 1.0 | 0.116 | 16% |
| Return Flow Non-Recoverable | 0.3 | 0.029 | 4% |



Source: Author's own elaboration.

The FtW tool also shows the four components of the FtW concept in a graphical way where the sizes of the arrows and blocks reflect the flow amount. In Figure 10, the left of the figure shows a typical surface/border system with large return flow and on the right is a typical sprinkler/drip system with smaller return flows.

FIGURE 10
**Screen showing input section and result section after entering inputs**


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

## 2.3 Input section

### 2.3.1 Irrigation system data

In the INPUT SECTION two numbers relevant for the entire irrigation system should be provided:

- Inflow ($m^3/s$)
- Length of growing season (days).

### 2.3.2 Irrigation block data

For each irrigation block the following data have to be provided:

- Name
- Area (ha)
- Water requirements (mm/d)
- Consumed fraction (percent)[5]
  - Consumed beneficial flows (percent)
  - Consumed non-beneficial flows (percent)
- Return flow fraction (percent)
  - Return flow recoverable (percent)
  - Return flow non-recoverable (percent).

The last terms are related to the REal WAter Savings in agricultural systems (REWAS) methodology as shown in Figure 10. Note that the return flow fraction should total 100 percent. The FtW tool adjusts automatically so that 100 percent will always be reached. For example, if a user changes the consumed fraction, the return flow fraction will change so that the total will remain 100 percent.

Finding correct numbers for those fractions is challenging. The FtW tool itself has four main irrigation technology default values. The document Reuse of water in agricultural systems – Follow the Water associated with this manual includes a literature review and data that might be used. Obviously, more accurate numbers that are location-specific require the collection of field data.

[5] We use the word "fraction" for clarity, although the unit is "percentage".

# 3. Exercise 1: Implementing the basic operations

In this exercise a simple **irrigation system** will be analysed with only one **irrigation block**.

Enter the following data:

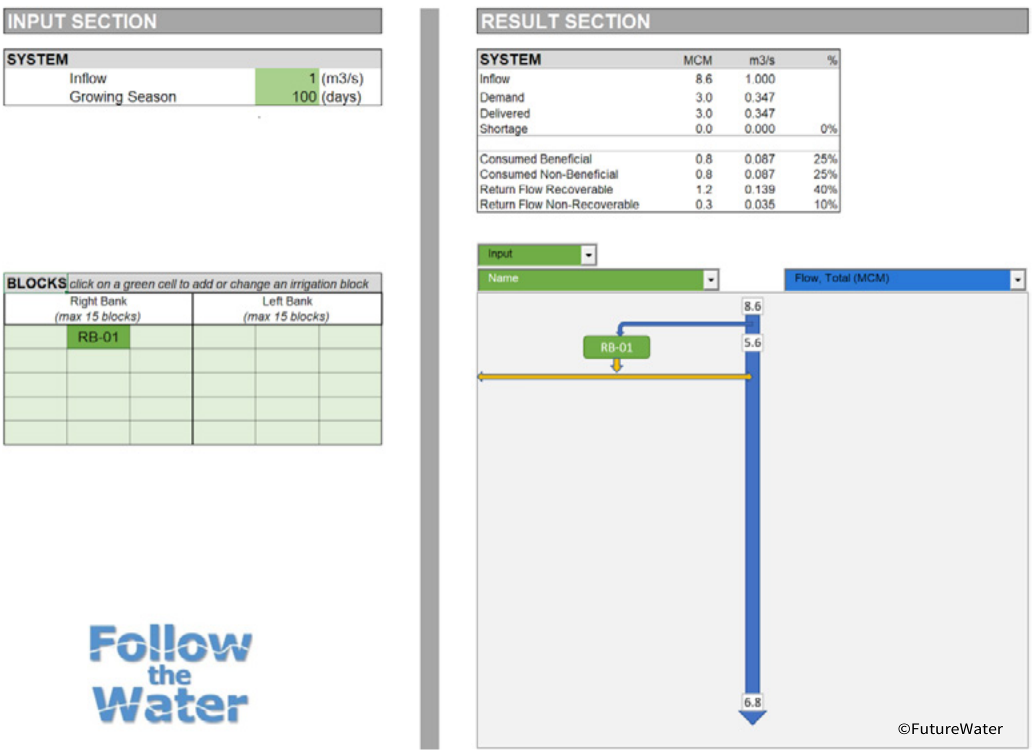
- System
  - inflow ($m^3/s$): 1
  - Growing season (days): 100
- Block
  - Mouse click on a light green cell
  - Area (ha): 500
  - Water requirements (mm/d): 10
  - Border irrigation

After entering these inputs the input section and result section should look like Figure 11b.

In the result section change the:

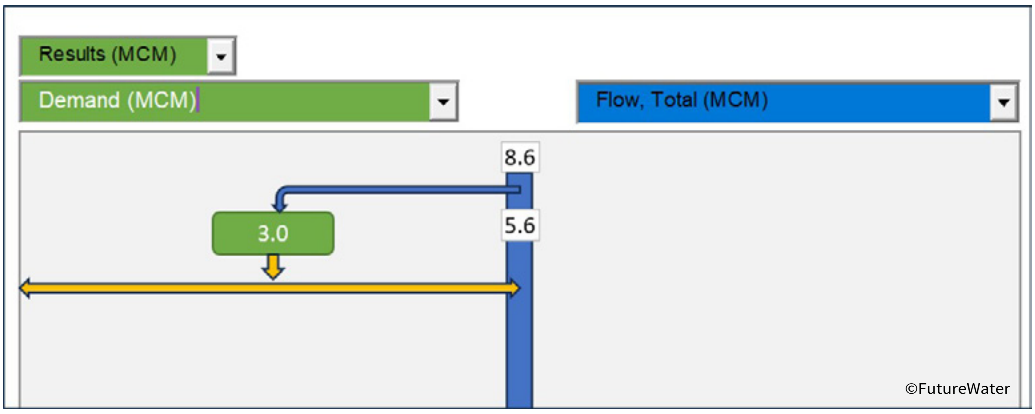
- top dark green drop box (shown here as “Input”) to “Results (MCM)”
- lower dark green drop box (shown here as “Name”) to “Demand (MCM)”

FIGURE 11A
**Screen showing input section and result section after entering inputs**




Source: Author's own elaboration.

FIGURE 11B
**Screen showing results section after entering inputs**




Source: Author's own elaboration.

Note: we use MCM for million cubic metres, that is 1 000 000 $m^3$

Finally, ensure that the blue drop box has "Flow, Total (MCM)" selected.

To enhance your understanding of the "Follow the Water" tool and the logic behind its quantitative assessments, a set of questions and answers is provided below. To maximize the learning experience, cover the answer sections and attempt to answer the questions yourself.

Q: Why is "Demand" 3.0 MCM?

Based on a quick calculation one would assume based on INPUT that:

10 mm/d * 100 days * 500 ha > 5.0 MCM

A: In INPUT it was mentioned that return flow fraction is 50 percent of which 80 percent is recoverable. So demand is 5 MCM – (5 MCM * 50 percent * 80 percent) = 3 MCM.

*Note that the above is based on the calculation algorithms and definitions of "crop water requirement" and "demand". A more elaborate discussion can be found in the Annex (Section A4).*

Q: Can you explain the three flows: 8.6 MCM; 5.6 MCM and 6.8 MCM shown in the main canal?

A:

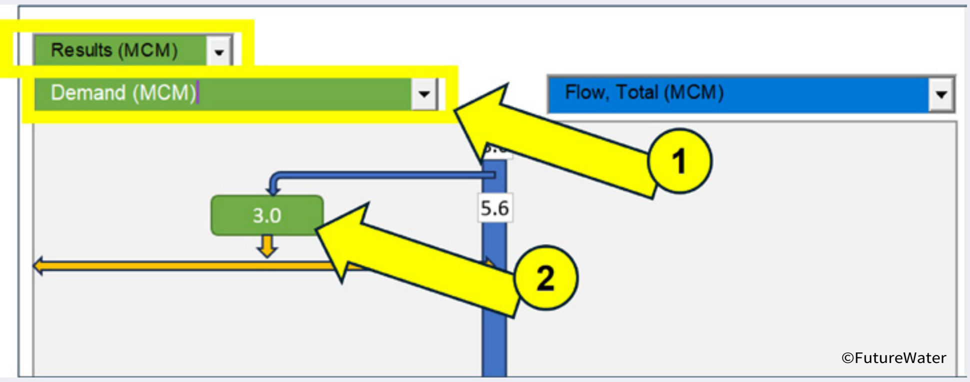
8.6 MCM is the total inflow as provided by the user: 1 $m^3/s$ * 100 days

5.6 MCM is the flow after 3.0 MCM is delivered to RB_01

6.8 MCM is the remaining 5.6 MCM in the canal plus return flow recoverable from RB_01

Task: Make water accounts in MCM for the irrigation block only (so not the entire system). This can be done by setting the first (dark green) drop down box to Results and subsequently changing the second drop down box (1) to various outputs (see Figure below). Read the values as shown in the irrigation block (2) in Figure 12.

FIGURE 12
**Screen showing results section when setting water accounts in MCM for irrigation block onlys**




Source: Author's own elaboration.

Specify IN:

Delivered =

Specify OUT:

Consumed Beneficial = ...

Consumed Non-Beneficial = ...

Return Flow Recoverable = ...Return Flow Non-Recoverable = ...

Check whether IN = OUT

Results:

IN = 3.00 MCM

OUT = 3.00 MCM

Specify OUT:

Consumed Beneficial = 0.75 MCM

Consumed Non-Beneficial = 0.75 MCM

Return Flow Recoverable = 1.20 MCM

Return Flow Non-Recoverable = 0.30 MCM

IN = OUT > correct

OUT = ...

Specify OUT:

Consumed Beneficial = ...

Consumed Non-Beneficial = ...

Return Flow Recoverable = ...

Return Flow Non-Recoverable = ...

Check whether IN = OUT

Result:

IN = 8.64 MCM

OUT = 8.64 MCM

Specify OUT:

Consumed Beneficial = 0.75 MCM

Consumed Non-Beneficial = 0.75 MCM

Return Flow Recoverable = 6.84 MCM > = Outflow

Return Flow Non-Recoverable = 0.30 MCM

# 4. Exercise 2: Changing irrigation technology

Change the type of irrigation technology to explore what the differences are in terms of water flow.

- Mouse click on the dark green cell in the input section, that was created in the previous exercise [RB_01] (Figure 11).
- Select as irrigation technology "Sprinkler".

Q: What is the percentage [consumed beneficial] for sprinkler irrigation?

A: 70 percent

Q: Why did "Demand" increase from 3.0 MCM to 3.8 MCM?

A: In INPUT it was mentioned that return flow reduced to 30 percent. Given this decrease in return flow that can be reused the demand increased.

Border (exercice 1):

5 MCM – (5 MCM * 50 percent * 80 percent) = 3.0 MCM.

Sprinkler (this exercise):

5 MCM – (5 MCM * 30 percent * 80 percent) = 3.8 MCM.

Explore what happens with the consumed beneficial water flows for the irrigation block under the two irrigation types (border versus sprinkler).

Mouse click on the dark green cell in the input section to change the irrigation system.

Q: How much is the consumed beneficial for border irrigation and for sprinkler?

A:

For border irrigation: 0.8 MCM

For sprinkler: 1.9 MCM

Q: Try to explain those differences. Both in common words as well as in calculations.

A:

In words:

Sprinkler irrigation provides water more effectively to the root water system than does border irrigation. Plant water uptake will therefore be higher.

In numbers:

Consumed Beneficial = Delivered * Consumed Fraction * Consumed Beneficial

For border irrigation: 3.0 * 50 percent * 50 percent = 0.8 MCM

For sprinkler irrigation: 3.8 * 70 percent * 70 percent = 1.9 MCM

Note: It seems contradictory that shifting from border irrigation to sprinkler irrigation will increase water consumption. There is however ample empirical as well as theoretical evidence that this is the case. A quick search on the internet of REWAS or "real water savings" and research in various FAO reports will reveal such empirical evidence.

For simplified theoretical evidence see Table 1 and calculate the two missing values.

TABLE 1
**Missing values for calculation**

| Field 1 | | border | drip |
|---|---|---|---|
| Crop water requirement | (mm/d) | 10 | 10 |
| Irrigation efficiency | (%) | 50% | 70% |
| Consumed | (mm/d) | 5 | 7 |
| Return flow | (mm/d) | 5 | 3 |
| Recoverable fraction | (%) | 80% | 80% |
| Return flow | (mm/d) | 4 | 2.4 |
| **Field 2, 3, 4, 5, 6, …** | | | |
| Crop water requirement | (mm/d) | 10 | 10 |
| From upstream | (mm/d) | 4 | xxx |
| **Demand** | **(mm/d)** | **6** | **xxx** |

Source: Author's own elaboration.

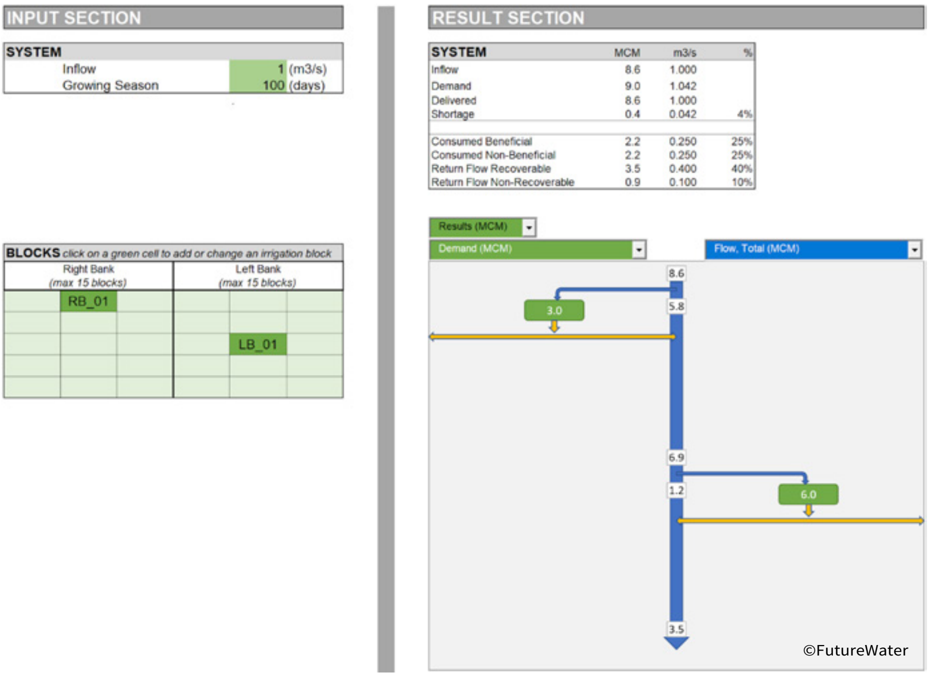
Answer for calculation of missing values:

From upstream: 2.4 mm/d

Demand: 7.6 mm/d

# 5. Exercise 3: Adding another irrigation block

FIGURE 13
**Input section and result section after introducing new irrigation block**




Source: Author's own elaboration.

In reality, an irrigation system has more than one irrigation block. Create another irrigation block at the left bank canal.

- Mouse click on a light green cell
- Area (ha): 1 000
- Water requirements (mm/d): 10
- Border irrigation.

Ensure that the previously created irrigation block (RB_01) is also set to [Border Irrigation]

After entering this new irrigation block, the input section and result section should appear as in Figure 13.

At the top of the result section, numbers are for the entire irrigation system (in this case for the two irrigation blocks).

Q: How much is the water shortage for the entire irrigation system (in MCM and in percent)?

A: 0.4 MCM; 4 percent

Q: Why is there still outflow from the system and at the same time there is a water shortage?

A: Total demand is 9 MCM and total inflow is 8.6 MCM. So the system manager conceives a shortage of 4 percent: 100 percent - (8.6/9.0). This calculated shortage is distributed equally to the two irrigation blocks.

Return flows and water remaining in the main canal contribute to this system outflow.

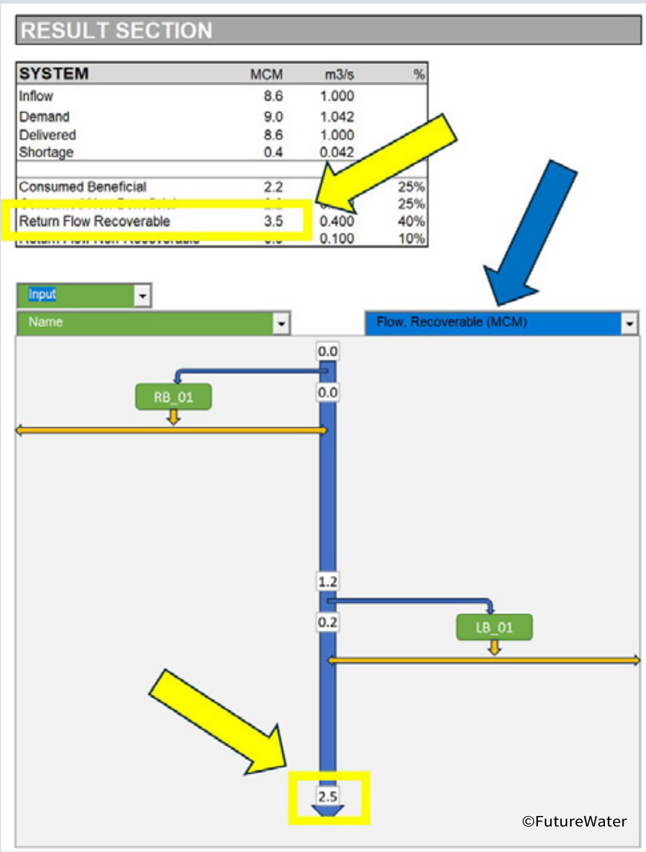
Q: Below is a copy of Figure 14 in which "Flow, Recoverable" is selected in the blue drop-down menu. Why is the value for "Return Flow Recoverable" (3.5 MCM) shown for the entire System different from the "Flow, Recoverable" shown for the main canal (2.5 MCM)?

A: The value of 3.5 MCM represents total internal return flows within the irrigation system, so the sum of RB_01 and LB_01. In contrast, the "Flow, Recoverable" outflow from the main canal (2.5 MCM) represents the portion of return flow that can be potentially used by downstream users.

Figure 14 illustrates this distinction:

- The ""Return Flows Recoverable" arrow represents the outflow from the main canal.
- The "Reuse within spatial domain" arrow corresponds to the reuse within the system. In this specific case the reuse of RB_01 water by LB_01.

FIGURE 14
**The return flows for the entire irrigation system**




Source: Author's own elaboration.

# 6. Exercise 4: Comparing border irrigation with sprinkler irrigation

Change the irrigation system for both irrigation blocks from border to sprinkler and compare the water flows.

Task: Analyse both scenarios and complete the following table for the entire system.

| | Border | Sprinkler |
|---|---|---|
| Demand (MCM) | | |
| Shortage (MCM) | | |
| Consumed Beneficial (MCM) | | |
| Outflow (MCM) | | |

Results:

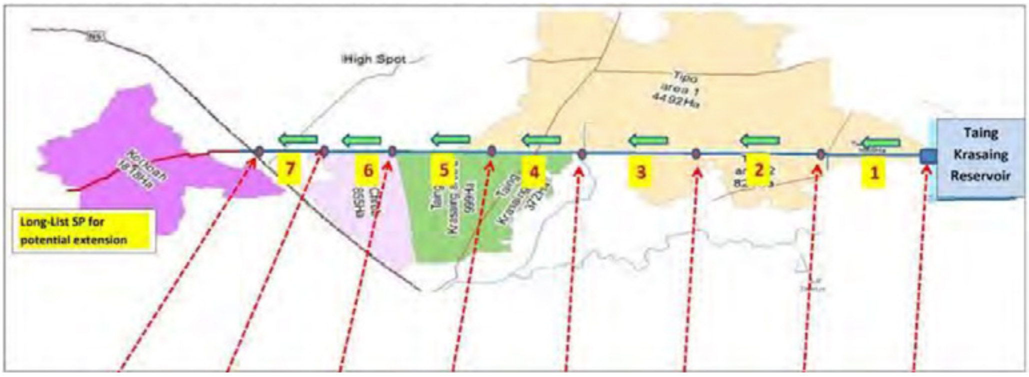
| | Border | Sprinkler |
|---|---|---|
| Demand (MCM) | 9.0 | 11.4 |
| Shortage (MCM) | 0.4 | 2.8 |
| Consumed Beneficial (MCM) | 2.2 | 4.2 |
| Outflow (MCM) | 3.5 | 2.1 |

Q: Explain why the outflow for the sprinkler option is lower than the border option?

A: The main reason is that the Consumed Beneficial is higher, so water remaining as return flow is lower. Keep in mind that the higher Consumed Beneficial is positive for the farmer: higher crop water use means in most cases higher yield and more income.

# 7. Case Study: Taing Krasaing Irrigation System (Cambodia)

FIGURE 15
**Schematic map of Taing Krasaing Irrigation System**




Source: Asian Development Bank (ADB). 2015. *Cambodia: Uplands Irrigation and Water Resources Management Project*. Feasibility Studies of Taing Krasaing Irrigation System and Prek Chik Irrigation System.

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

TABLE 2
**Main irrigation blocks in the Taing Krasaing Irrigation System, Cambodia**

| Name | Area (ha) | Left or Right Banks[6] |
|---|---|---|
| Private firms | 2 664 | Right 1 500 ha<br>Left 1 164 ha |
| Tipou | 2 989 | Right |
| CAVAC | 1 370 | Left |
| Chroab | 855 | Right |
| Korkoah | 1 991 | Right 991 ha<br>Left 1 000 ha |
| **Total** | **9 869** | |

Source: Asian Development Bank (ADB). 2015. Cambodia: Uplands Irrigation and Water Resources Management Project. Feasibility Studies of Taing Krasaing Irrigation System and Prek Chik Irrigation System.

This case study is based on Asian Development Bank (2015). The Taing Krasaing irrigation system (Figure 14) is located in Kampong Thom Province in Cambodia. The system consists of one main canal and five offtake points serving five irrigation blocks.

[6] Some of those data are mentioned in the ADB report and are estimates based on maps.

The following data have been extracted from ADB (2015):

- two growing seasons, total 240 days (page 3)
- "irrigation efficiencies" (page 3, p. 48[7]):
    - 10 percent at start of project[8]
    - 40 percent after ten years
- crop water requirements: 6 mm/d (page 4)
- irrigation water requirements: 1.5 l/s/ha (page 45) > 13 mm/d
- increase in crop water requirements in 35 years: 35 percent (page 4)
- canal inflow: 14 $m^3s$ (page 34)
- canal maximum flow: 84 $m^3/s$ (page 35).

Note that it is reported that there is quite a lot of pumped groundwater use within portions of the Cambodia Agricultural Value Chain Program (CAVAC) command area. To avoid complexity this will be ignored in the following exercises shown in Figures 16 and 17.

Task 1: Create a FtW schematic with the data mentioned above. For the moment consider that all irrigation blocks use border irrigation.

Make a screenshot of the schematic developed (Figure 15).

Results:

**INPUT SECTION**

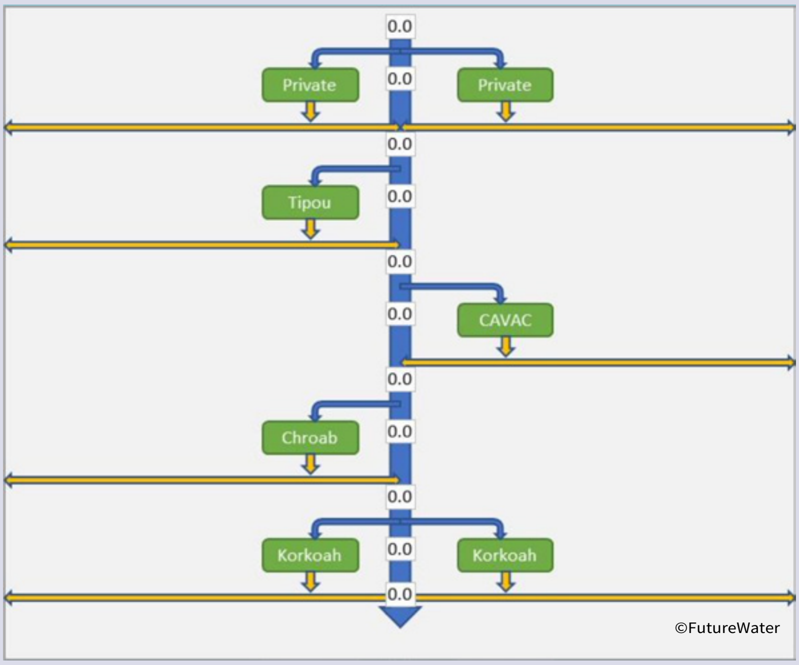
| **BLOCKS** *click on a green cell to add or change an irrigation block* | | | | | |
|---|---|---|---|---|---|
| Right Bank *(max 15 blocks)* | | | Left Bank *(max 15 blocks)* | | |
| | | Private | Private | | |
| | | Tipou | | | |
| | | | CAVAC | | |
| | | Chroab | | | |
| | | Korkoah | Korkoah | | |

[7] Efficiency terms used are: ec = conveyance, ed = distribution, ea = field application, et = total.

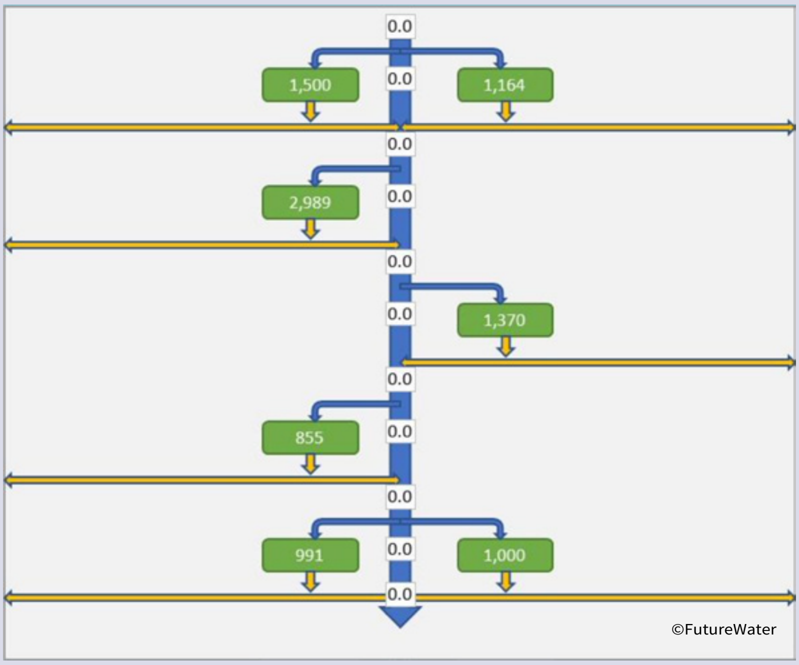
[8] This is an exceptionally low value. However, since this is documented we will use this value here.

FIGURE 16
**Schematics for Task 1 for Cambodian case study**

**RESULT SECTION (Name selected)**




**RESULT SECTION (Area selected)**

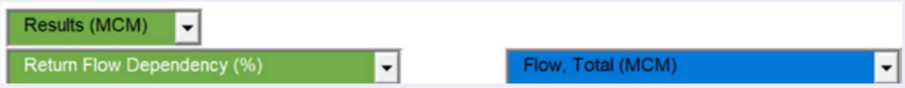



Source: Author's own elaboration.

Task 2: Make a screenshot showing the:

(i) irrigation block's (green) return flow dependency (%)

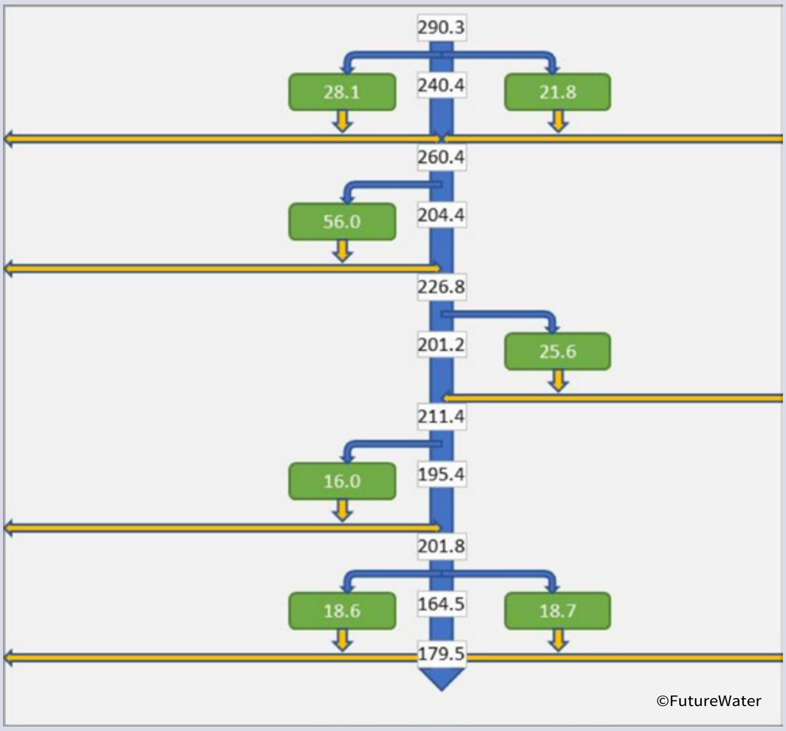
(ii) the total flow (MCM) for the canal (blue) (Figure 16).




Results:

FIGURE 17

**Screen shot for Task 2 for Cambodian case study**




Source: Author's own elaboration.

Select the option "Flow, Recoverable (MCM)]" for the canal (blue)

Q: Why is this recoverable flow shown in the schematic (53.3 MCM) smaller than the number shown in the system summary (73.9 MCM)?

A: The number shown in the system summary includes the internal recoverable return flows, whereas the outflow of the entire system does not.

This can be verified by selecting the recoverable return flows for the irrigation blocks (green) and sum all the numbers.

The total recoverable return flows are 73.9 MCM of which 53.3 MCM flows out of the system. So internally a total of 20.6 MCM (73.9 MCM – 53.3 MCM) is applied to the various irrigation blocks.

Select for the "irrigation blocks" (green) option for the return flow dependency (%).

Q: What is the return flow dependency for the Korkoah irrigation blocks?

A: 23 percent

Q: Why is the outflow for the sprinkler option lower than the border option?

A: The main reason is that the Consumed Beneficial is higher, so water remaining as return flow is lower. Keep in mind that the higher Consumed Beneficial fraction is positive for the farmer: higher crop water use means in most cases higher yield and more income.

According to the Asian Development Bank (2015) report the water requirements will increase by 35 percent as a result of climate change. Therefore increase to 17.5 mm/d (13 + 13*35 percent) for all irrigation blocks.

System inflow will be reduced from 14 m3/s down to 10 m3/s

Task 3: Analyse both scenarios and complete Table 3 for the entire system

TABLE 3
**Water requirements for entire irrigation system in Cambodian case study**

| | Current | Climate Change |
|---|---|---|
| Demand (MCM) | | |
| Shortage (MCM) | | |
| Consumed Beneficial (MCM) | | |
| Outflow (MCM) | | |

Results:

| | Current | Climate Change |
|---|---|---|
| Demand (MCM) | 185 | 249 |
| Shortage (MCM) | 0 | 41 |
| Consumed Beneficial (MCM) | 46 | 52 |
| Outflow (MCM) | 180 | 83 |

Source: Author's own elaboration.

For the climate change scenario a shortage of 41 MCM exists and at the same time 83 MCM flows out of the system.

Q: Why is there a water shortage and at the same time water flows out of the irrigation system?

A: For any irrigation type some water will not be consumed and therefore outflow will always occur.

Task 4: Assume that for all irrigation blocks the irrigation technology will change from border to sprinkler and apply this change for the climate change scenario (so inflow is 10 m3/s and crop water requirement is 17.5 mm per day).

Analyse both scenarios and complete Table 4 for the entire system.

TABLE 4
**Water requirements for entire irrigation system in Cambodian case study for different irrigation technologies**

| | Border | Sprinkler |
|---|---|---|
| Demand (MCM) | | |
| Shortage (MCM) | | |
| Consumed Beneficial (MCM) | | |
| Outflow (MCM) | | |

Results:

| | Border | Sprinkler |
|---|---|---|
| Demand (MCM) | 249 | 315 |
| Shortage (MCM) | 41 | 108 |
| Consumed Beneficial (MCM) | 52 | 102 |
| Outflow (MCM) | 83 | 50 |

Source: Author's own elaboration.

Task 5: Make a screenshot of the FtW diagrams for the two irrigation technologies. This is shown in Figure 18.

Results:

FIGURE 18
**Screenshot of the Follow the Water diagrams for the two irrigation technologies**


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

Q: What are the consequences of those changes in irrigation technology for farmers within the irrigation blocks and for downstream users below the irrigation system?

A:

Farmers within the irrigation blocks will produce more food as their Beneficial Consumption water increases. An economic analysis should justify whether the investment in the sprinkler irrigation system outweighs the higher crop production.

Users downstream of the irrigation system will receive less water as more water is consumed within the system.

So instead of water being saved by changing from border irrigation to sprinkler irrigation, more water will be consumed. An economic analysis and a full basin analysis are required to compare the advantages and disadvantages.

# 8. Case Study: Karnataka, India

This case study is based on DHV (2013). The Gondhi Anicut Irrigation System in Karnataka, India is a small scheme of 4 600 ha constructed between 60 years and 90 years ago with a 74.4 km main canal on the right bank (4 253 ha) and 14.5 km on the left bank (212 ha). There are 20 tanks in the command. The overall objective of the project was to modernize the irrigation infrastructure so that a fully functioning irrigation system is in place. Details can be found in the feasibility study document (DHV, 2013).

A baseline model will be built using the Follow the Water (FtW) tool. Most data can be found in the feasibility study, although some data are missing and will be replaced by data based on expert knowledge. In summary, the data shown in Table 5 will be used.

TABLE 5
**Data for Karnataka case study (India)**

| Right Bank | Left Bank |
|---|---|
| Head: 2 400 ha | Head: 100 ha |
| Middle: 1 000 ha | Middle: 50 ha |
| Tail: 1 000 ha | Tail: 50 ha |
| **Total: 4 400 ha** | **Total: 200 ha** |

Source: Adapted from DHV (2013)

Season: Dry season (November to April)

- 100 days growing season

Crop water requirements

- Take the dry season paddy crop for all irrigation blocks with crop water requirement of 20.7 mm/d (Table 32 in the feasibility study > 20 742 $m^3$/ha for 100 days)

Irrigation technology

- Border irrigation

Inflow in main canal

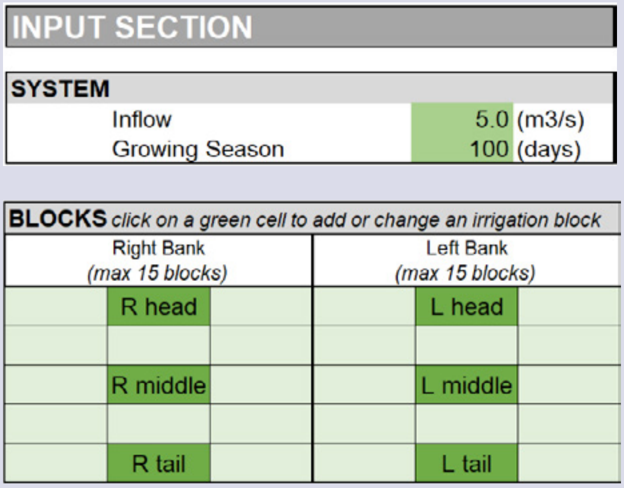
- 5 $m^3$/s

Task 1: Create an FtW schematic with the data as mentioned above and make a screenshot of the schematic. This is shown in Figure 19.

Results:

INPUT SECTION

FIGURE 19
**Schematic for the Follow the Water approach for Karnataka case study (India)**



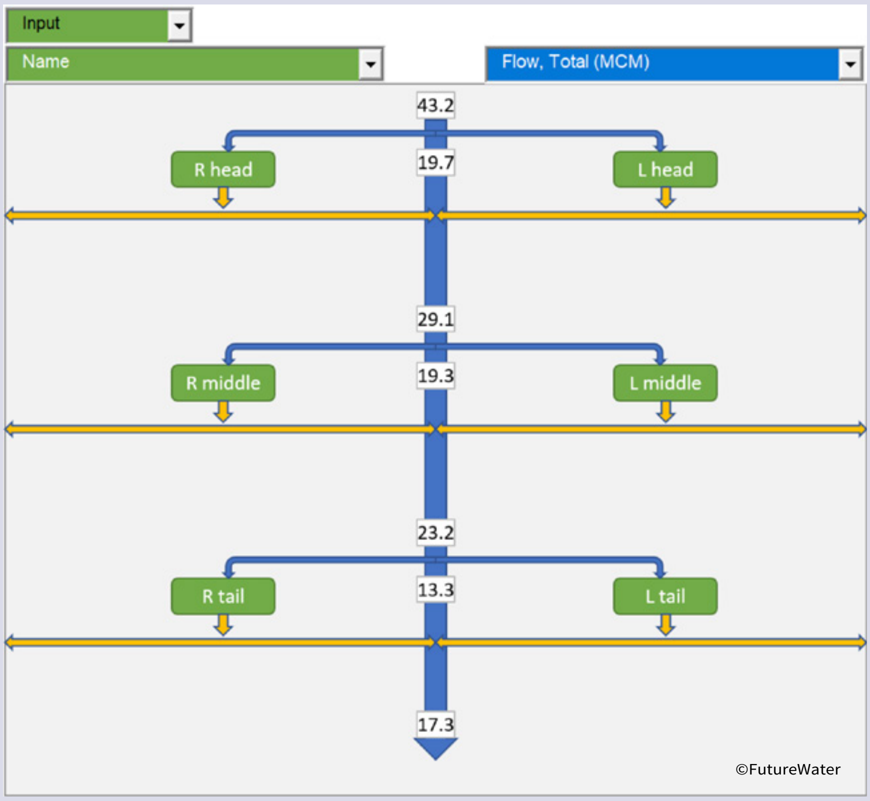
INPUT SECTION

| SYSTEM | | |
|---|---|---|
| Inflow | 5.0 | (m3/s) |
| Growing Season | 100 | (days) |

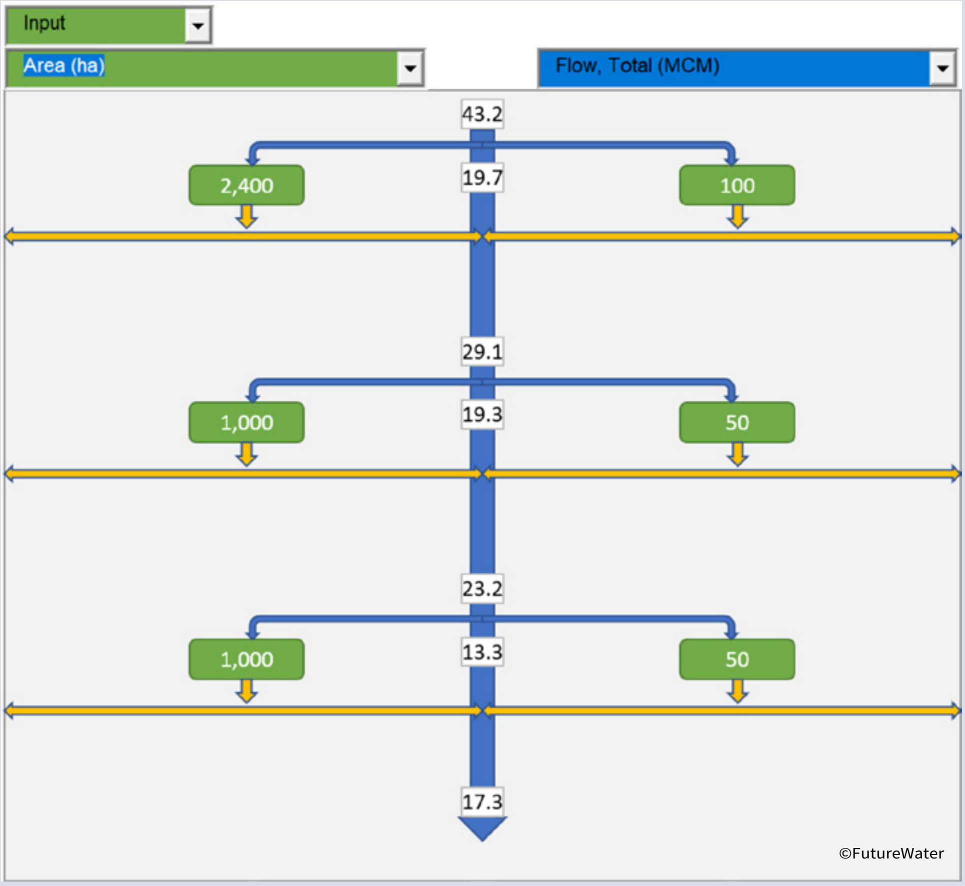
BLOCKS *click on a green cell to add or change an irrigation block*

| Right Bank (max 15 blocks) | | | Left Bank (max 15 blocks) | | |
|---|---|---|---|---|---|
| | R head | | | L head | |
| | | | | | |
| | R middle | | | L middle | |
| | | | | | |
| | R tail | | | L tail | |

RESULT SECTION (Name selected)



RESULT SECTION (Area selected)




Source: Author's own elaboration.

Q: How much is the water shortage?

Look in the feasibility study to find an explanation (page 49, bullet point 185)

A: 13.9 MCM which is about 24 percent.

According to bullet point 185 in the feasibility study (DHV,2013), the extent to which a change in allocation represents a change in supply is unknown because of lack of data on the current quantity of water either supplied or being returned to the river.

According to Table 32 of the feasibility study (DHV, 2013), dry season paddy requires 20 741 $m^3$/ha. This is 20.7 mm/d (100 days). If paddy cultivation is no longer practiced (Table 33) crop water requirements will change. To demonstrate we assume that the entire area will be under areca nut (14.5 mm/d).

Areca nut is normally not irrigated by border irrigation, so for this exercise there is a change to furrow irrigation technology.

Task 2: Compare the system results for the original paddy cultivation and the new areca nut cultivation and discuss the main differences. See Table 5.

**Table 5.** Comparison of paddy cultivation and areca nut cultivation water requirements

Results:

Paddy

| SYSTEM | MCM | $m^3/s$ | % |
|---|---|---|---|
| Inflow | 43.2 | 5.000 | |
| Demand | 57.1 | 6.613 | |
| Delivered | 43.2 | 5.000 | |
| Shortage | 13.9 | 1.613 | 24% |
| | | | |
| Consumed Beneficial | 10.8 | 1.250 | 25% |
| Consumed Non-Beneficial | 10.8 | 1.250 | 25% |
| Return Flow Recoverable | 17.3 | 2.000 | 40% |
| Return Flow Non-Recoverable | 4.3 | 0.500 | 10% |

Areca nut (furrow)

| SYSTEM | MCM | $m^3/s$ | % |
|---|---|---|---|
| Inflow | 43.2 | 5.000 | |
| Demand | 45.4 | 5.250 | |
| Delivered | 43.2 | 5.000 | |
| Shortage | 2.2 | 0.250 | 5% |
| | | | |
| Consumed Beneficial | 15.6 | 1.800 | 36% |
| Consumed Non-Beneficial | 10.4 | 1.200 | 24% |
| Return Flow Recoverable | 13.8 | 1.600 | 32% |
| Return Flow Non-Recoverable | 3.5 | 0.400 | 8% |

Source: Adapted from DHV. 2013. Feasibility Report for the Karnataka Integrated and Sustainable Water Resources Management Investment Program. Project Preparation Technical Assistance: ADB TA 7954-IND. Asian Development Bank.

Task 3: Evaluate the impact of changing the areca nut irrigation technology from sprinkler to drip. See Table 6 and Figure 20.

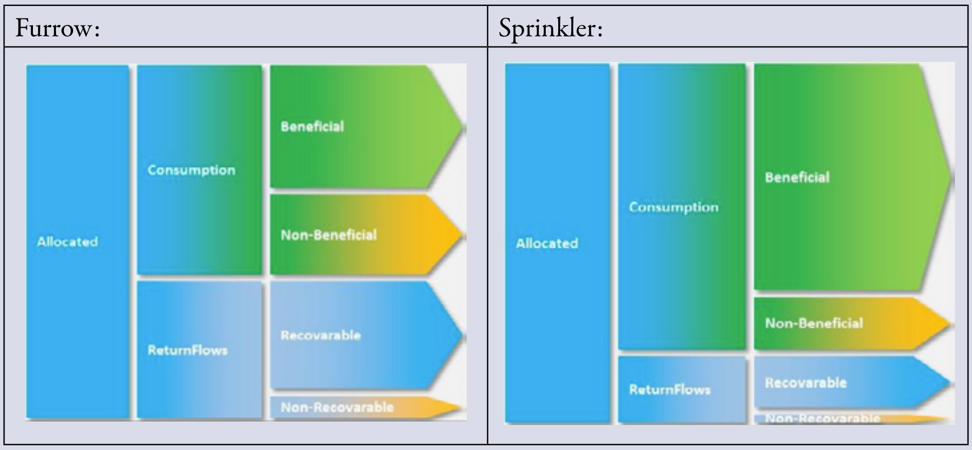
**Table 6.** Impact of changing irrigation technology on water requirements for areca nut

Result: Areca nut (sprinkler):

| SYSTEM | MCM | $m^3/s$ | % |
|---|---|---|---|
| Inflow | 43.2 | 5.000 | |
| Demand | 50.7 | 5.867 | |
| Delivered | 43.2 | 5.000 | |
| Shortage | 7.5 | 0.867 | 15% |
| | | | |
| Consumed Beneficial | 21.2 | 2.450 | 49% |
| Consumed Non-Beneficial | 9.1 | 1.050 | 21% |
| Return Flow Recoverable | 10.4 | 1.200 | 24% |
| Return Flow Non-Recoverable | 2.6 | 0.300 | 6% |

Source: Adapted from DHV. 2013. Feasibility Report for the Karnataka Integrated and Sustainable Water Resources Management Investment Program. Project Preparation Technical Assistance: ADB TA 7954-IND. Asian Development Bank.

FIGURE 20
**Impact of changing irrigation technology on water requirements for areca nut**




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

Q: How much should the inflow be to make sure that no water shortage occurs?

Clue: Increase the system inflow stepwise until no water shortage occurs.

A: About 5.9 $m^3/s$.

Task 4: Think about some scenarios you would like to analyse and describe these and summarize the results.

Results:

# 9. Follow the water using the Water Evaluation and Planning (WEAP) tool

The FtW tool helps irrigation-related professionals to 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 aimed at persons in training and education contexts, and in the initial design of irrigation systems.

In cases where more elaborate analyses are required, one could use more advanced integrated water resources modelling tools. One of those tools is the Water Evaluation and Planning (WEAP) tool. WEAP is a software tool for integrated water resources planning. It provides a comprehensive, flexible and user-friendly framework for water resources planning. WEAP was developed by the Stockholm Environment Institute (SEI) and can be used free of charge for the majority of users.

It is assumed that some basic knowledge of WEAP exists. If lacking, one can use the "WEAP in one hour" tutorial, which can be found at https://www.weap21.org/index.asp?action=213.

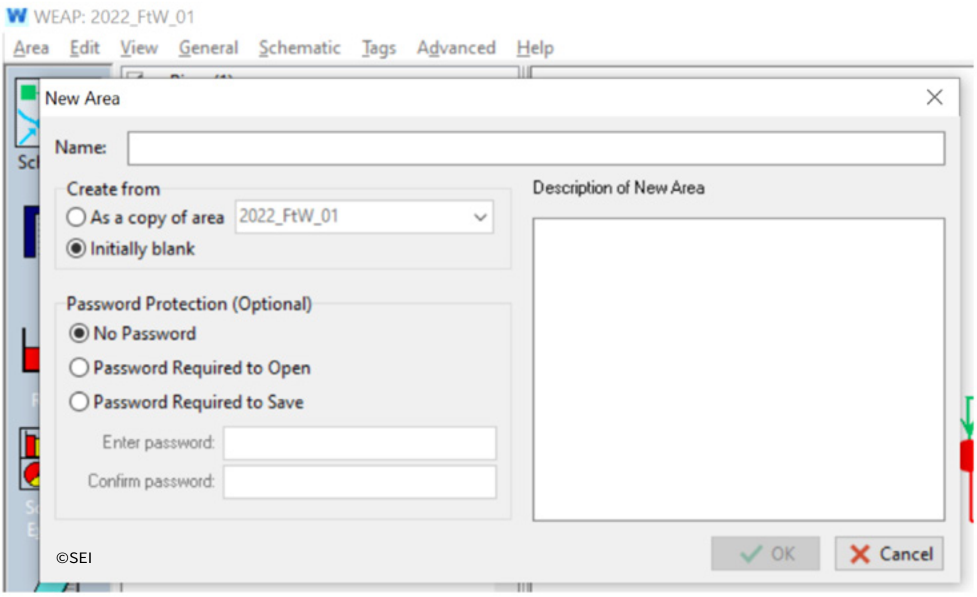
## 9.1 Exercise:

This WEAP exercise mimics the first exercise of the FtW tool (Chapter 3: Exercise 1: Implementing the Basic Operations (in this report)). This exercise demonstrates that exactly the same results will be obtained. It also shows that the complexity of WEAP is much greater than the FtW tool. Furthermore, the WEAP model can be easily expanded to analyse more complex systems.

### 9.1.1 Create a new WEAP schematization

Create a new WEAP area: > Area > New Area (see Figure 21)

FIGURE 21
**Creation of new area for WEAP exercise**

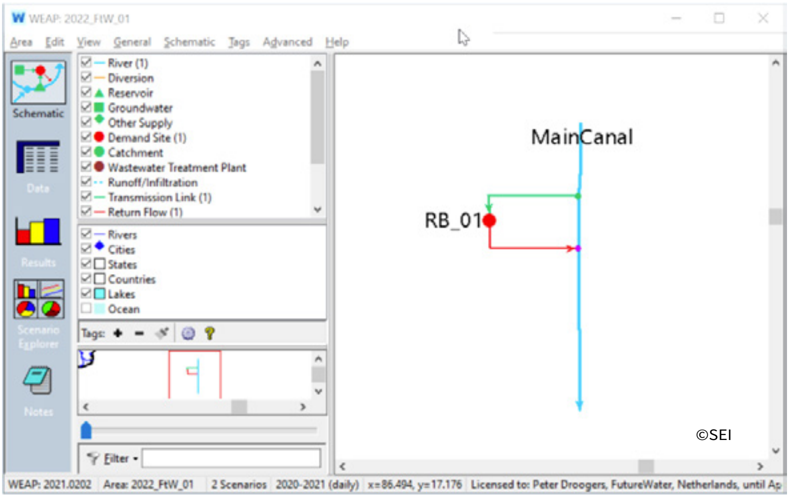



Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

The boundaries of the new area are irrelevant so just select an area anywhere you choose (even in an ocean is allowed!).

### 9.1.2 Add nodes

FIGURE 22
**Schematization showing addition of new nodes**




Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

Add the following nodes to the new area (Figure 22):

- River > this is the main canal
- Demand Site > this is the irrigation block
- Transmission Link > this is the irrigation canal (or pipeline)
- Return Flow > this is the drain

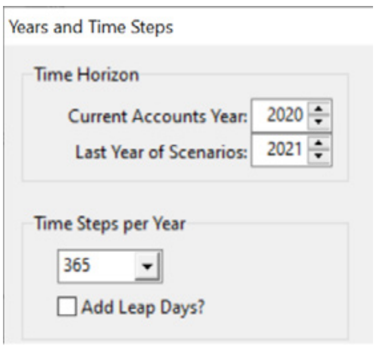
The schematization should look something like this:

### 9.1.3 Set timestep and years

> General > Years and timestep

(Make sure the "Add Leap Days?" option is not selected) (Figure 23)

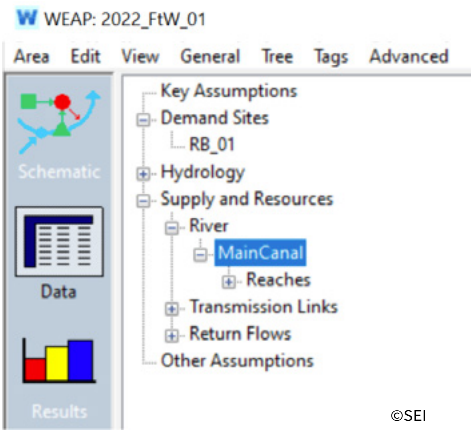
FIGURE 23
**Years and time steps**




Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

### 9.1.4 Flow entering in the main canal

FIGURE 24
**Schematic showing key assumptions**




Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

In Exercise 1: Implementing the Basic Operations (Chapter 3 this report) an inflow of 1 m3 /s- was assumed and a growing season of 100 days. The same data will be entered in WEAP.

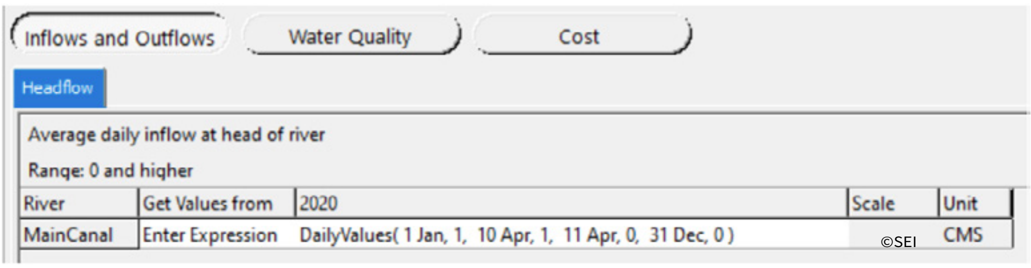
> Data > Supply and Resources > River > Main Canal

Key assumptions are shown in Figure 24.

Enter a headflow of 1 CMS for 100 days. This can be done by using the Daily Time Wizard, or entering the following function:

Daily Values (1 Jan, 1, 10 Apr, 1, 11 Apr, 0, 31 Dec, 0) (see Figure 25).

FIGURE 25
**How to enter a headflow of 1 CMS for 100 days**



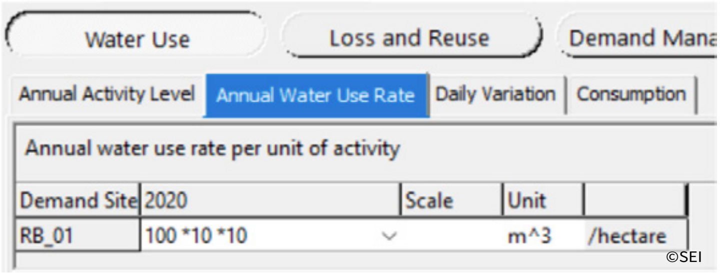

Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

### 9.1.5 Irrigation block water demand

In Exercise 1: Implementing the Basic Operations (Chapter 3 this report), the following assumptions were made:

- Area: 500 ha
- Water demand: 10 mm/d

FIGURE 26
**Annual water rate per unit of activity**




Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

This can be implemented in WEAP by:

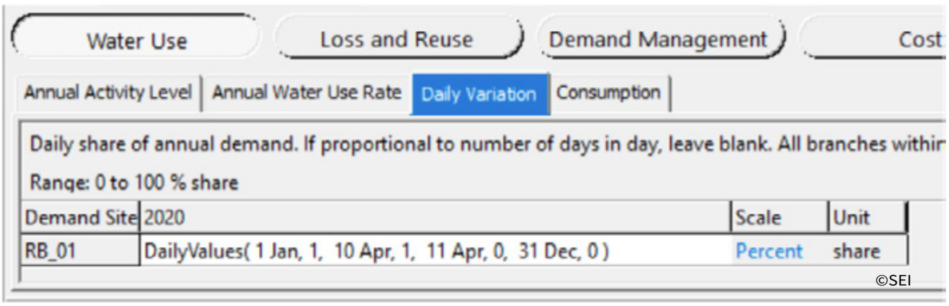
> Data > Demand Sites > RB_01 > Water Use > Annual Activity Level > 500 ha

Data > Demand Sites > RB_01 > Water Use > Annual Water Use Rate > 100*10*10 m3 /ha

where the first 100 is for 100 days, the first 10 is mm/d, and the second 10 is the conversion from mm/d to m3/ha (see Figure 26)

Since WEAP is based on annual values, daily variation has to be defined. The simulation is set up for 100 days, so that means every day, 1 percent of the annual water demand takes place on a daily basis (Figure 27).

FIGURE 27
**Defining daily variation in water rate per unit of activity**




Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

### 9.1.6 Irrigation technology

Border irrigation was assumed with a consumed fraction of 50 percent

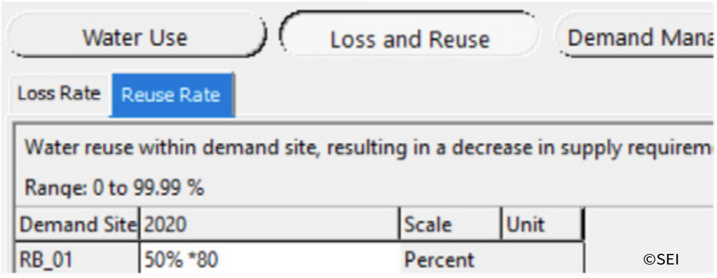
> Data > Demand Sites > RB_01 > Water Use > Consumption > 50 percent

Return flow was assumed to be 50 percent, of which 80 percent is recoverable.

> Data > Demand Sites > RB_01 > Loss and Reuse > Reuse Rate > 50 percent * 80

Note that input should be in  percent. Therefore use 50 percent * 80. Or one can enter directly 40 (Figure 28).

FIGURE 28
**Water reuse rate within demand site**

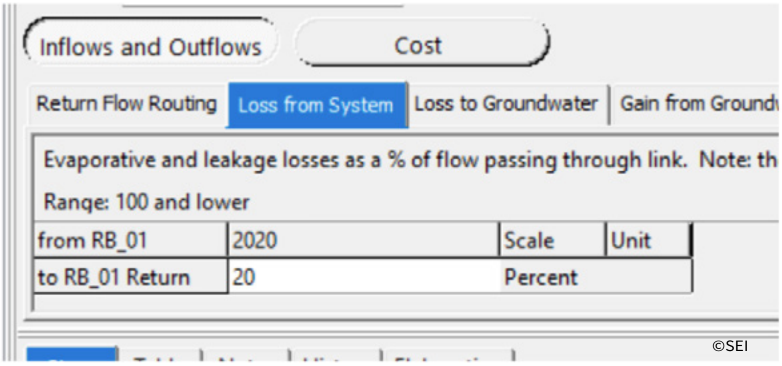



Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

Non-recoverable return flows were assumed to be 20 percent
> Data > Return Flows > from RB_01 to RB_01 Return > Loss from system > 20 percent (Figure 29).

### Return flows

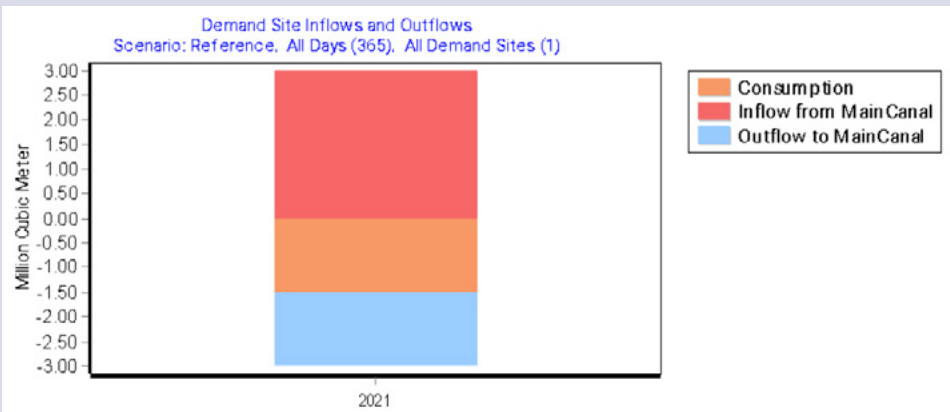
FIGURE 29
**Showing 20 percent loss from system**

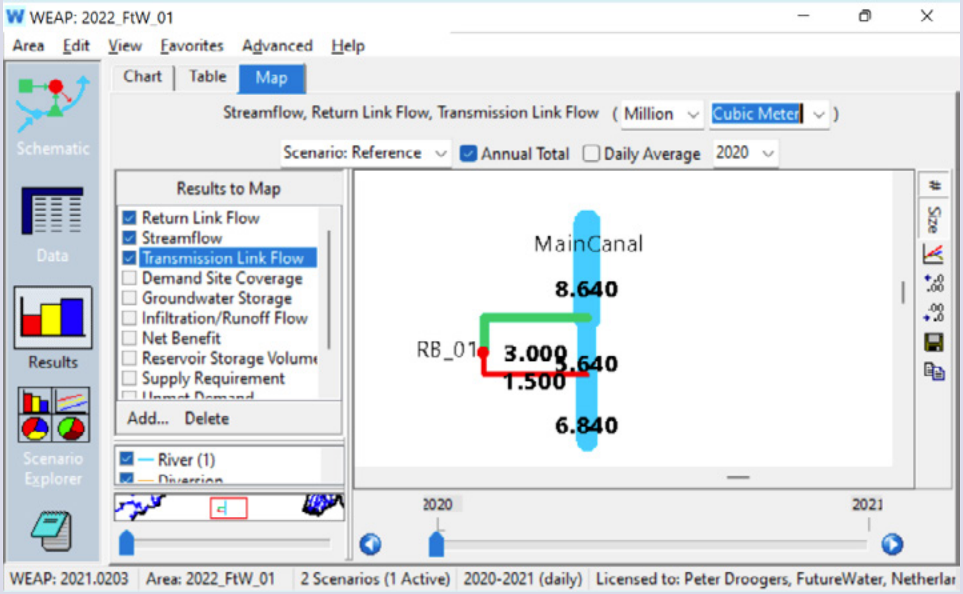


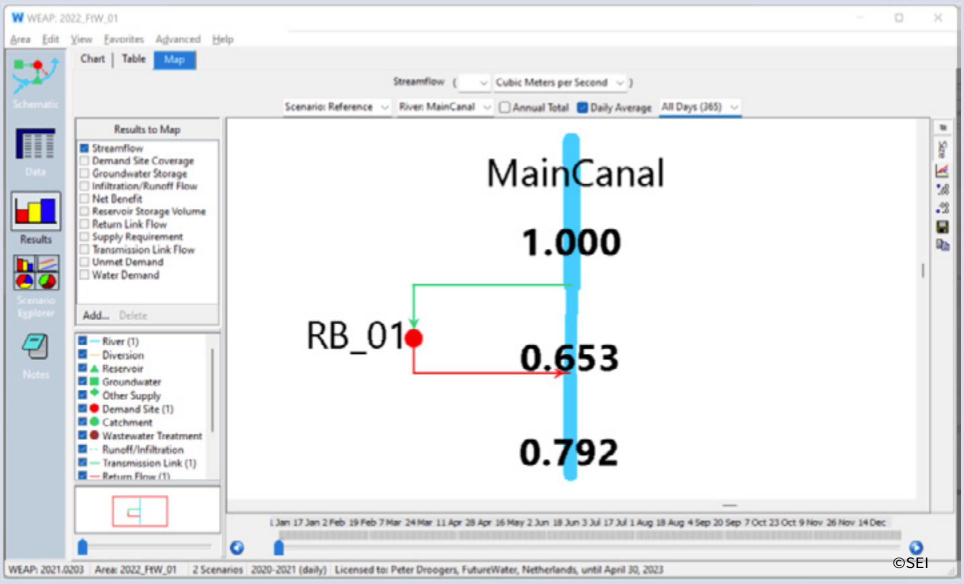

Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

FIGURE 30
**Charts for use in Task 1**

Task 1: Produce the charts shown in Figure 29 by yourself and copy and paste here.






Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

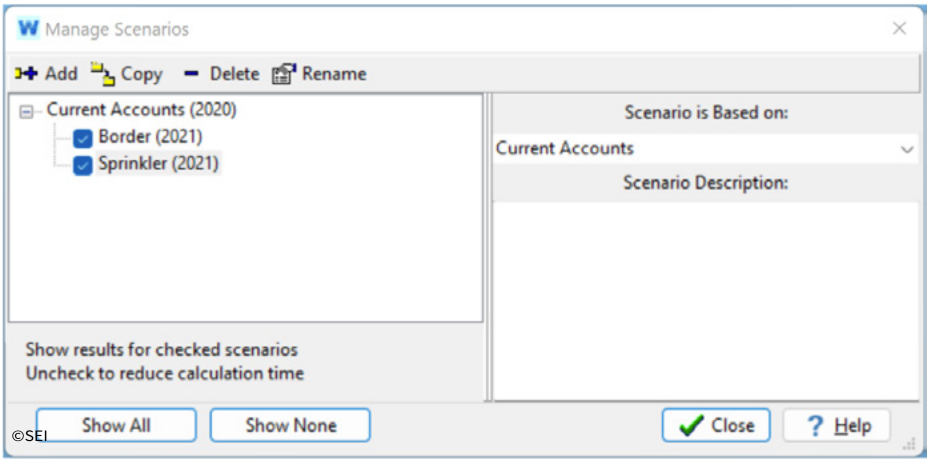
Results:

Task 2: Compare the results from WEAP and from the FtW tool. Make sure the results are the same.

Results:

# 10. Water evaluation and planning: Change in irrigation technology

FIGURE 31
**Screenshot for defining a new scenario “Sprinkler”**



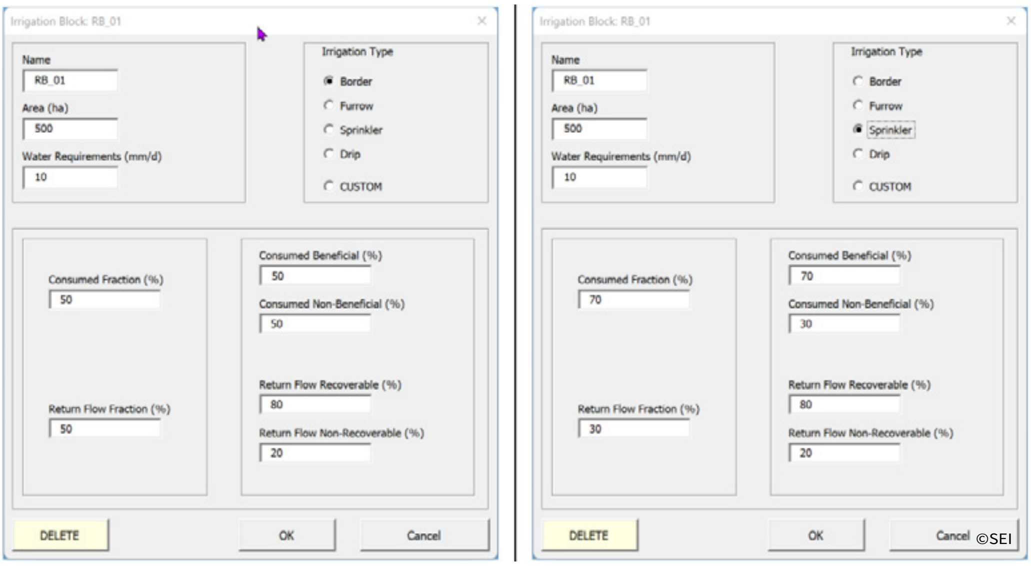

Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

This WEAP exercise mimics the second exercise of the FtW tool (Chapter 4: Exercise 2: Changeing Irrigation Technology (this report)).

In WEAP, define a new scenario called “Sprinkler” (Figure 31).

Figure 32 presents a copy of the two types of irrigation (border and sprinkler) as defined in the FtW tool.

FIGURE 32
**Screenshot showing border and sprinkler types of irrigation as defined in the Follow the Water tool**




Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

Enter the following data for the new scenario:

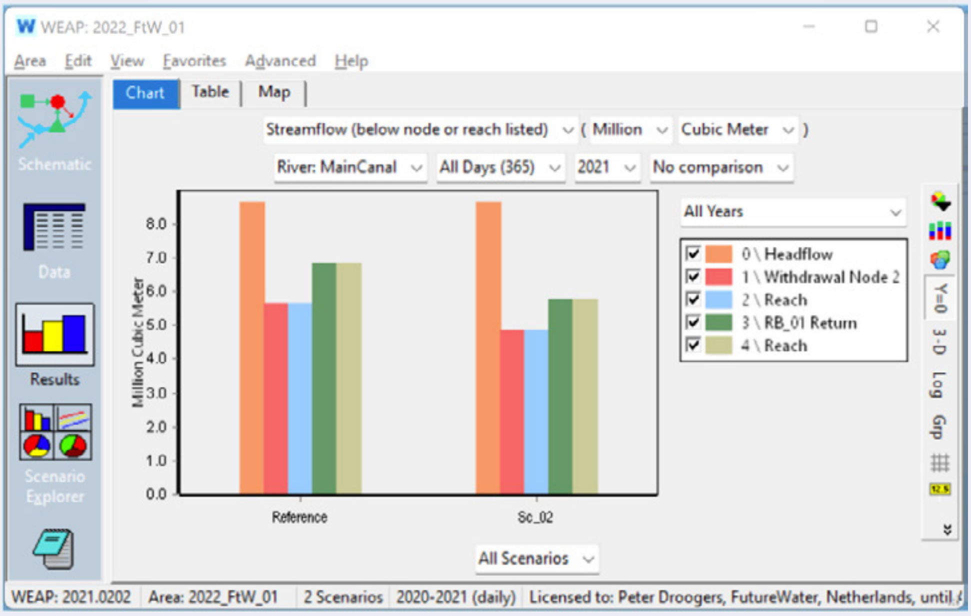
> Data > Demand Sites > RB_01 > Water Use > Consumption > 70 percent

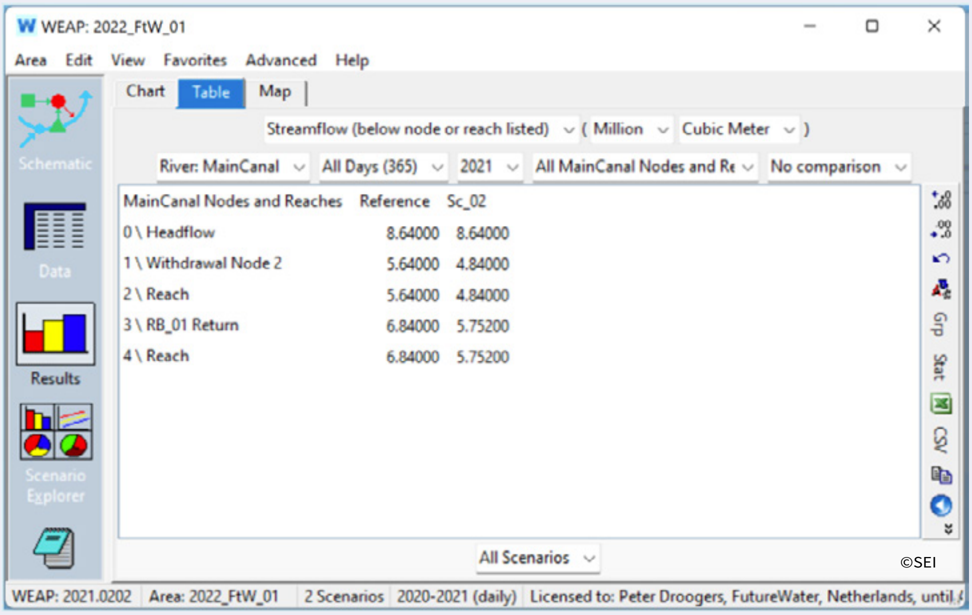
> Data > Demand Sites > RB_01 > Loss and Reuse > Reuse Rate > 30 percent * 80

FIGURE 33

**Charts for use in Task 3**

Task 3: Produce the charts shown in Figure 32 by yourself and copy and paste here




Source: Stockholm Environment Institute. n.d. *Water Evaluation And Planning (WEAP).* [Accessed 29 March 2020]. https://www.weap21.org/index.asp?action=8

Results:

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# 10. Comments and responses/ Questions and answers

**During the use of the Follow the Water (FtW) tool various comments (C) and questions (Q) were raised. The most relevant ones that might be helpful for other users are presented here along with responses (R) and answers (A).**

C:
Input side: Inflow in main canal is usually not constant throughout the season (to cope with low

FIGURE A1
**Showing Unhide option to reveal supporting sheets**

and peak flows). I suggest you can enter monthly data here or peak/average flow.

R:
Good point. FtW was developed to undertake scoping analysis rather than creating a detailed design plan. Other tools are more suited to the detailed design of irrigation systems.

C:
Input side: It is unclear if the growing season is for main crops, or for when water is flowing in the main canal.

R:
Correct. It is considered that the cropping season is similar to the water delivery period.

C:
I think different blocks (and even within blocks) may have different growing seasons. Perhaps add a comment here to explain what needs to be entered as growing season.

R:
FtW was developed to undertake scoping analysis rather than creating a detailed design plan. Other tools are more suited if crops and/or growing seasons differ between irrigation blocks.

Q:
Input side: I don't understand how the water requirements and area relates to the blocks entered below. Are water requirements the average for all blocks and within blocks?

A:
FtW considers that crops and water requirements within one block are similar.

Q:
Input side: I find the entering of the system (secondary and blocks) confusing and can be cumbersome. For instance, the system I worked on in Utah had four secondary canals but many (>100) tertiary blocks. Do all of these need to be entered manually or can they be grouped or replicated?

A:
Grouping tertiary blocks into similar units is advised in those cases. In fact, the approach of a block is scale independent; it can be a few fields up to thousands of hectares.

C:
It might be useful to think of alternative ways to enter the system set-up, for example: 1) a WEAP approach with nodes and links; 2) a pop-up with input form; 3) a database with tertiary units, connected secondary canals, and requirements/area.

R:
We would like to keep FtW simple. Indeed for more detailed analysis one could consider WEAP or a similar package. The intention of developing FtW was never to replace existing tools/models, but to be unique in terms of ease of operation.

Q:
The part on consumed (non) beneficial and recoverable fraction probably needs guidance to enter or will this information come from elsewhere REWAS? Guidance return flows?

A:
The associated guidance document "Reuse of water in agricultural systems – Follow the Water " can be used for this.

Q:
How do we consider the effect of soil moisture storage below the rootzone: in some cases it can be substantial to the point of eliminating actual return flow to drains, water courses or groundwater – arid and semi-arid conditions with deep soils and deep water tables – such as alluvial valleys?

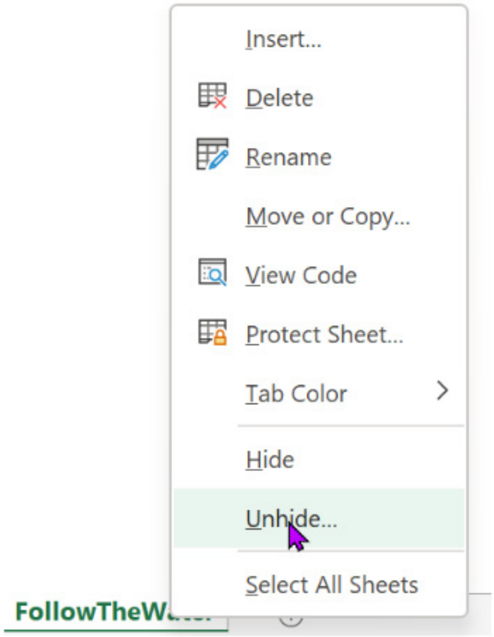
A:
This is indeed not included in the FtW tool. If those processes are an important factor, one could consider using a more physically-based model in addition to the FtW.

# Annex: Under the Hood

In this Annex the underlying implementation of the Follow the Water (FtW) tool will be briefly summarized to enable advanced users to make necessary changes in the coding.

## A1. Workbook sheets

The FtW tool has a couple of supporting sheets that are hidden by default for users.
To unhide: Right-Click on sheet name at the bottom and select Unhide (Figure A1).




The three sheets:

- FollowTheWater
  - The main sheet
  - VBA code name: shtMain
- Calculations (hidden)
  - All calculations are undertaken in this sheet
  - VBA code name: shtCalcs
- shtMenu (hidden)
  - The links to the various Menu items
  - Can be changed and after restarting Menus are updated
  - VBA code name: shtMenu

## A2. Subroutines, functions

(obtained by using [GetAllSubNames.xlsm])

Some additional comments for the most relevant routines.

ShtMain.ComboBoxMain_Change

ShtMain.ComboBoxIrri_Change

ShtMain.ComboBoxFlow_Change

ShtMain.Worksheet_Activate

ShtMain.Worksheet_SelectionChange

Do something if clicked

Draw.DeleteAllShapes

Draw.DrawBox

Draw.DrawCanalMain

Draw.DrawBentArrow

Draw.FormatShapeBlock

Draw.DrawIrriSystem

Draw.ShapeTextFormat

Draw.DrawFlowTextBox

Draw.ComboBoxPosition

Make sure combo boxes are in correct position and sizes

Called by shtMain.Worksheet_Activate

Draw.DrawAll

Draw.GroupShapes

Draw.ExcelCalcsDisable

Draw.ExcelCalcsEnable

DropDowns.ShowLabelsIrri

DropDowns.ShowLabelsFlow

DropDowns.DrawLabelsIrri

DropDowns.DrawLabelsFlow

DrawRewasM.DrawRewasBox

DrawRewasM.DrawRewasAllocated

DrawRewasM.DrawRewasRectangle

DrawRewasM.DrawRewasArrow

DrawRewasM.ShapeArrowSize

DrawRewasM.ShapeAddSpace

DrawRewasM.ShapeFormatting

DrawRewasM.DrawRewas

DrawRewasM.TestDrawRewas

frmInput.UserForm_Initialize

frmInput.optBorder_Click

frmInput.optFurrow_Click

frmInput.optSprinkler_Click

frmInput.optDrip_Click

frmInput.FillIrrigationType

frmInput.UserForm_Activate

frmInput.btnCancel_Click

frmInput.btnOK_Click

frmInput.btnDelete_Click

frmInput.IN_Area_Exit

frmInput.IN_Cons_Exit

frmInput.IN_Retu_Exit

frmInput.IN_ConsBene_Exit

frmInput.IN_ConsNonBene_Exit

frmInput.IN_RetuRecov_Exit

frmInput.IN_RetuNonRecov_Exit

frmInput.OnlyNumbers

DebugCode.loopShapesAllSheet

DebugCode.loopShapesAllCurrentSheet

## A3. Water demand calculation algorithms

Most of the calculation algorithms in the FtW tool are straightforward. Users can get full access to those calculations by un-hiding the sheet [Calculations] as explained in Section A1.

Definitions are key in this respect and an important consideration is the notion of efficient irrigation systems. It is well documented that under similar conditions more advanced irrigation technologies (sprinkler, drip) consume more water and have lower return flows. Water requirements for those advanced irrigation technologies are affected by two contrasting processes:

- **less** water needs to be delivered to the irrigation system as **return flows are lower**
- **more** water needs to be delivered to the irrigation system as **plant uptake is higher**.

In FtW this is implemented by:

Demand = Crop Water Requirements – Return Flow Recoverable

## A4. Water demand and consumption under improved irrigation technologies

There are many real-world examples showing that introducing improved irrigation technologies (e.g. from border to drip) water consumption and demand are increasing. The FtW tool demonstrates this. These somewhat counterintuitive findings can be explained relatively easily, as demonstrated below.

Consider one field where a change is considered from border to drip irrigation technology. The water balance (in mm) is shown in Table A1.

**Table A1.** Water balance when field is changed from border to drip irrigation technology

| Field 1 | | border | drip |
|---|---|---|---|
| Crop water requirement | (mm/d) | 10 | 10 |
| Irrigation efficiency | (%) | 50% | 70% |
| Consumed | (mm/d) | 5 | 7 |
| Return flow | (mm/d) | 5 | 3 |
| Recoverable fraction | (%) | 80% | 80% |
| Return flow | (mm/d) | 4 | 2.4 |

However, this one particular field is connected to many other fields. The reduction in return flows as a result of increased consumption will lead to higher demand for the entire system (Table A2 ).

**Table A2.** Results showing higher demand for entire system

| Field 2, 3, 4, 5, 6, … | | | |
|---|---|---|---|
| Crop water requirement | (mm/d) | 10 | 10 |
| From upstream | (mm/d) | 4 | 2.4 |
| **Demand** | **(mm/d)** | **6** | **6** |

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