National rainwater harvesting (RWH) tool for horticultural production in polytunnels and glasshouses

User guidance manual

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Background

Polytunnels and glasshouses are used extensively within the soft fruit and ornamental horticulture sectors, which are important parts of the rural economy, and entirely dependent on irrigation. In recent years there has been a growing interest in the potential for rainwater harvesting (RWH) systems to be used in polytunnel and glasshouse production to reduce dependence on public mains water supplies, to reduce the need to treat surfacewater for irrigation and to reduce runoff risks.

Working with growers and key stakeholders, and building on earlier work with Kent County Council, researchers from Cranfield University have designed and developed a simple Microsoft Excel-based tool to help growers and farm business advisors evaluate the potential hydrological performance and water storage effectiveness of RWH systems to support investment decision making within Great Britain. The national-scale tool was designed to be simple and intuitive to use and requires only a limited set of readily-accessible input data.

This manual provides step by step guidance on how to use the new RWH tool and how to interpret the outputs. The tool operates on standard specification desktops and laptops and only requires the user to have Excel installed on their computer and to have a basic understanding of how to navigate around Excel.

RWH tool functionality

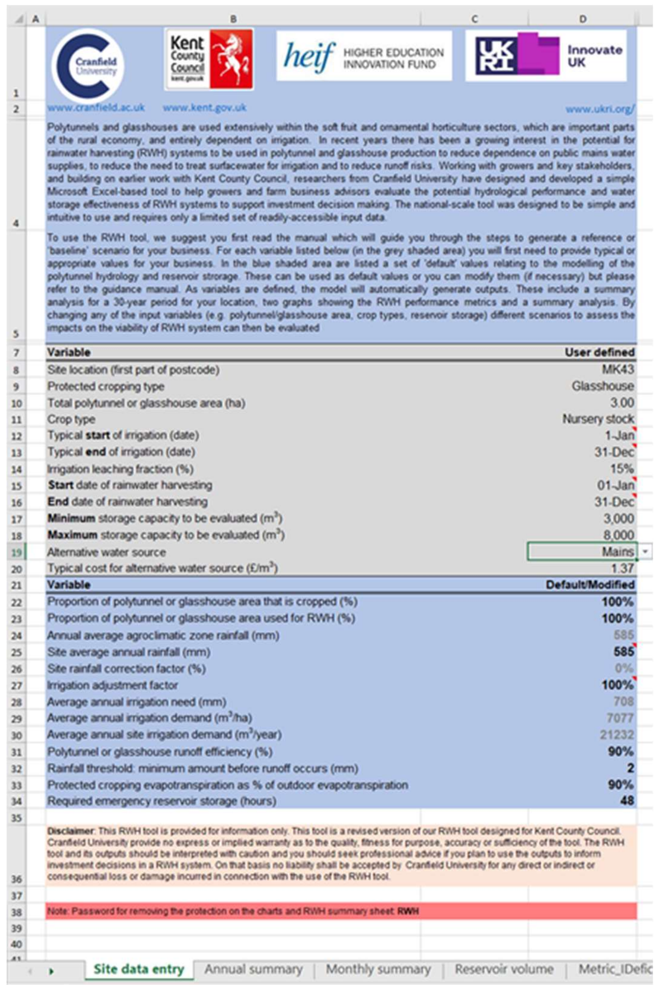
The RWH tool was designed to assist horticultural businesses improve their decision-making regarding how best to incorporate RWH into their water management practices. The tool will support you in calculating the most effective RWH system for your circumstances, taking into account local climate as well as business information on irrigated and rainwater harvesting areas, crop/plant types and available water storage. The RWH tool can be used to:

- assist businesses with existing RWH installations to evaluate the performance of their systems and to identify measures to improve rainwater self-sufficiency;
- enable businesses that do not have RWH systems to evaluate the potential irrigation water resource benefits, including design and management options, and mains water saving costs, and;
- assist others involved in design of RWH systems for new polytunnel and glasshouse developments to make informed decisions regarding trade-offs between RWH performance and water storage capacity to recommend systems best suited to local circumstances.

Getting started (Overview)

Download the Excel RWH tool from www.d-risk.eu to your computer and open the Excel workbook file by double clicking on the filename or opening it directly from Excel. Excel may show a "Security warning" that macros have been disabled. This refers to automated set of actions within the RWH tool that perform some of the calculations. If this warning appears, please click on "Enable Content".

The RWH tool has 7 separate sheets, each labelled with a grey tab at the bottom of the page (e.g. Site data entry) as shown in the panel below. Of the 7 worksheets, 4 worksheets (Annual summary; Metric_IDeficit; Metric_WSEfficiency, and RWH summary) are password protected and cannot be edited.



In order to use the RWH tool, the user first needs to complete the Site data entry form.

For each variable in the **grey shaded area** you will need to provide appropriate values for your business.

In the **blue shaded area** are listed a set of 'default' values in bold text relating to the modelling of the polytunnel/glasshouse hydrology and reservoir storage. You can leave these as 'default values' or you can modify them based on your own experience or technical knowledge. The grey values in this box are model inputs (average annual rainfall) and outputs (irrigation need/demand) to help you decide whether to modify the 'default' values

As the variables are entered in the grey or blue shaded box, the model will automatically generate a set of RWH outputs. These include analyses based on 30 years of recent daily weather data for your location ("Annual summary", "Monthly summary" and "Reservoir volume" tabs), two graphs showing the RWH performance metrics (Metric_IDeficit and Metric_WSEfficiency) and an overall summary analysis (RWH summary).

By changing any of the input variables on the Site data entry sheet (such as the polytunnel area, RWH area, the crop type, reservoir storage volume), different scenarios to assess the impacts on the viability of a RWH system for your business can be evaluated.

The following pages provide a step-by-step guide to completing the Site Data entry sheet and how to interpret the results.

Site data entry

The first step is to provide data values (user-defined and default variables) for the site and its location. The details of the user-defined and default variables and their explanation are provided in Annex 1.

Grey shaded area

7	Variable	User defined
8	Site location (first part of postcode)	MK43
9	Protected cropping type	Glasshouse
10	Total polytunnel or glasshouse area (ha)	3.00
11	Crop type	Nursery stock
12	Typical **start** of irrigation (date)	1-Jan
13	Typical **end** of irrigation (date)	31-Dec
14	Irrigation leaching fraction (%)	15%
15	**Start** date of rainwater harvesting	01-Jan
16	**End** date of rainwater harvesting	31-Dec
17	**Minimum** storage capacity to be evaluated (m^3)	3,000
18	**Maximum** storage capacity to be evaluated (m^3)	8,000
19	Alternative water source	Mains
20	Typical cost for alternative water source (£/m^3)	1.37

For each variable you will need to provide appropriate values for your site. These include:

Site location. Type in the first half of your postcode. This is used to retrieve appropriate long-term weather data for your site.

Select whether polytunnels or glasshouses are your main **Protected cropping type**

Enter your **Total polytunnel or greenhouse area (ha)**

Using the dropdown menu select your main **Crop type**. Ten options are available covering soft fruit, salad vegetable and ornamental crops. Only one crop type can be selected.

For the crop type selected, enter the **Typical start of irrigation (date)** and **Typical end of irrigation (date)**[1].

Based on the crop type and your irrigation scheduling approach, enter the **Irrigation leaching fraction (%)**. This represents the percentage of the irrigation applied that is lost through drainage or run off.

Enter the **Start date of rainwater harvesting** which will normally be the 1st January for glasshouses and permanent polytunnels or the typical date when seasonal polytunnel covers are fitted. Similarly the **End date of rainwater harvesting** will normally be the 31st December for glasshouses and permanent polytunnels or the typical date when seasonal polytunnel covers are removed*.

The RWH tool assumes that rainfall collected from the polytunnel area will be stored in a reservoir. The tool provides output data and performance metrics for a range of storage capacities, so you need to define what should be the "**Minimum storage capacity to be evaluated (m^3)** and the **Maximum storage capacity to be evaluated (m^3).** These values can be changed after you have run the model for the first time. If you have a pre-existing reservoir, set its storage volume as the minimum storage capacity.

Any shortfall in water collected from the RWH system to meet irrigation demand is assumed to be met from either public mains supply, direct surface water abstraction (summer), or from an existing reservoir (lined or unlined) that is not part of the RWH. Using the dropdown menu, choose your appropriate **Alternative water source**. The typical cost for this alternative water source is automatically estimated, but it can be changed if you know the real cost.

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[1] Enter dates in the format DD/MM/YYYY (e.g. 01/04/2020). NB you can use any year.

Blue shaded area

	Variable	Default/Modified
21	**Variable**	**Default/Modified**
22	Proportion of polytunnel or glasshouse area that is cropped (%)	**100%**
23	Proportion of polytunnel or glasshouse area used for RWH (%)	**100%**
24	Annual average agroclimatic zone rainfall (mm)	585
25	Site average annual rainfall (mm)	**585**
26	Site rainfall correction factor (%)	0%
27	Irrigation adjustment factor	**100%**
28	Average annual irrigation need (mm)	708
29	Average annual irrigation demand (m^3/ha)	7077
30	Average annual site irrigation demand (m^3/year)	21232
31	Polytunnel or glasshouse runoff efficiency (%)	**90%**
32	Rainfall threshold: minimum amount before runoff occurs (mm)	**2**
33	Protected cropping evapotranspiration as % of outdoor evapotranspiration	**90%**
34	Required emergency reservoir storage (hours)	**48**

'Default' values are provided in this area in **bold**. These can be left unchanged or you can modify them, if necessary, based on the values in grey text.

Proportion of polytunnel or glasshouse area that is cropped (%) The tool assumes the all of the area is irrigated (100%) but this can be revised.

Proportion of polytunnel or glasshouse area used for RWH (%) The RWH tool assumes the whole roof area (100%) is used for RWH but this can be reduced.

Site average annual rainfall (mm): the RWH uses 30 years of daily weather data for the agroclimatic zone in which the site is located (based on the postcode) and shows the average annual rainfall for the zone. You can enter your local average annual rainfall to scale (increase or decrease) the agroclimatic zone input data.

Irrigation adjustment factor (%): the RWH tool makes necessary simplifications in simulating the site water balance, so the simulated average annual irrigation need (mm) and irrigation demand (in m^3/ha and m^3/year) are summarised (in grey). If your irrigation usage is very different to these values (e.g. due to differences in irrigation technology, crop mix etc), you can specify an irrigation adjustment factor – the RWH will automatically update the simulated average annual values.

Polytunnel or glasshouse runoff efficiency (%) This value is used to calculate the potential volume of rainwater that can be usefully collected from the polytunnel area. It is a function of reliable local rainfall and system configuration, as well as factors influencing runoff such as the polytunnel structure and size, slope, and the duration over which the polytunnel covers are used. See Annex 1 for further details.

Rainfall threshold: minimum amount before runoff occurs (mm) Not all rain that lands on a polytunnel can be collected, depending on the duration, intensity and amount of rainfall. Very small amounts of rain will not result in any runoff due to storage on the polytunnel, wind drift and evaporation. In this tool it was assumed that days with less than 2mm will not generate any runoff.

Polytunnel evapotranspiration as % of outdoor evapotranspiration: Crops grown under glass or plastic are subject to different (usually lower) levels of evapotranspiration (ET) compared to crops grown outdoors. Glass and plastic covers affect the incoming solar radiation, temperature, windspeed and humidity. It is therefore important to modify the reference evapotranspiration in the weather data to represent the conditions inside the polytunnel. See Annex 1 for further details.

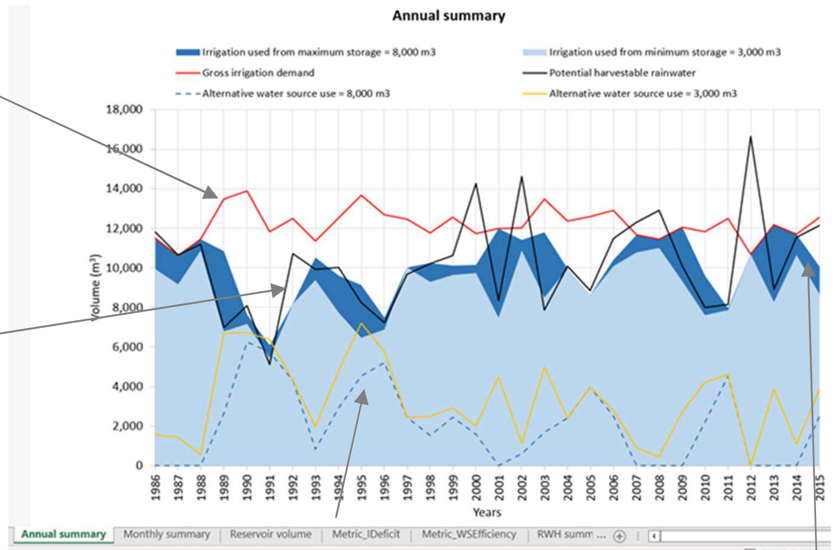
Required emergency reservoir storage (hours) Polytunnel and glasshouse cropping systems are highly vulnerable to any disruption in water supply for irrigation. It is therefore prudent for RWH systems to incorporate some temporary, short-term storage capacity to buffer against a supply failure. For a given storage capacity, the RWH model does not allow the reservoir storage to go below 2 days (48 hours) of simulated peak gross water demand[2].

[2] "Gross water demand" includes the crop water requirement plus the leaching requirement.

RWH analysis: Annual summary

Once all the user-defined variables have been added in the Site data entry sheet, the RWH tool will automatically generate a set of outputs. These include a summary analysis for a 30-year period (1986-2015) for the site location. An explanation of how the RWH tool uses the long-term daily weather data to drive a polytunnel hydrology model and to calculate irrigation demand is given in Annex 2. An example output for the annual summary is shown in the panel below.

This provides an annual summary for four key variables.



Volume of gross irrigation water demand (**red line**)

Volume of potentially harvestable rainfall that could be usefully collected from the structure (**black line**)

Volume of harvested rainwater used to meet irrigation demand for the selected minimum (**light blue shaded area**) and maximum (**dark blue shaded area**) storage capacities. Where the dark blue shaded area is not visible, it is the same as value for the minimum storage capacity

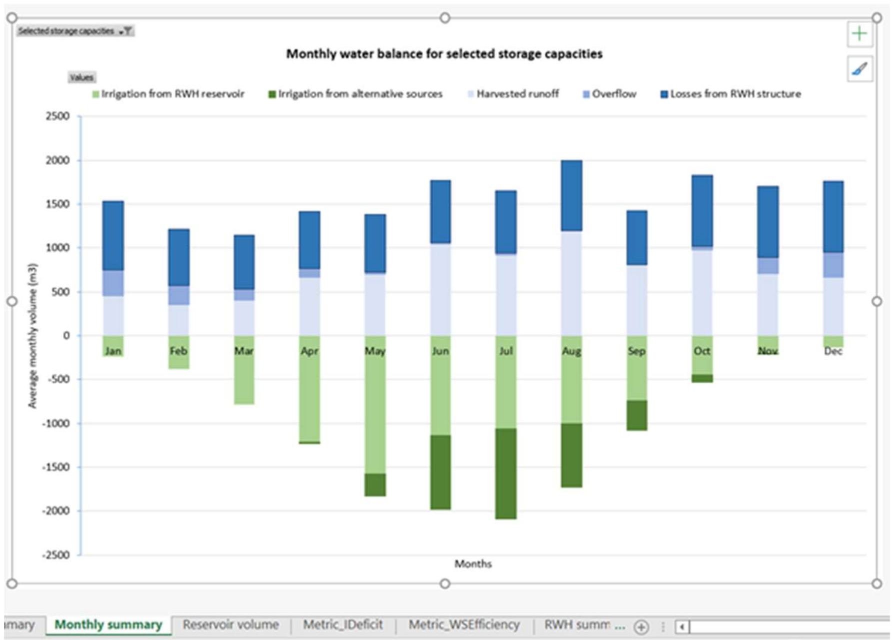
Volume of water used from the alternative source due to insufficient availability of harvested rainfall in the selected minimum (**yellow line**) and maximum (**dashed blue line**) capacity reservoir.

The figure shows that this site is unable to collect sufficient rainwater (**black line**) in most years to meet gross irrigation demand (**red line**). However, with the maximum storage capacity (8000m^3), the system is able to provide sufficient harvested rainfall (**dark blue shaded area**) to meet gross irrigation demand (**red line**) in e.g. 2007-2009 such that the alterative water use (**yellow line**) is sometime zero. With the minimum storage capacity (3000m^3), additional water from the alternative source (**dashed blue line**) is required in all years except 2012.

The RWH tool could be re-run with a larger maximum storage capacity or larger rainwater harvesting area to try to reduce or remove these deficit years.

RWH analysis: Monthly summary

The second summary shows average monthly outputs for the 30-year period (1986-2015) for the site location. An example output is shown in the panel below. The user can select the storage capacity for which outputs are shown by clicking on the grey “Selected storage capacities” in the upper left corner of the graph area.



This provides monthly outputs for five key variables.

Volume of irrigation from the RWH reservoir (**light green**)

Volume of irrigation from the alternative water source (**dark green**)

Volume of losses from the RWH structure (**dark blue**), representing rainfall that cannot be potentially harvested due to evaporation, wind drift, gutter performance etc

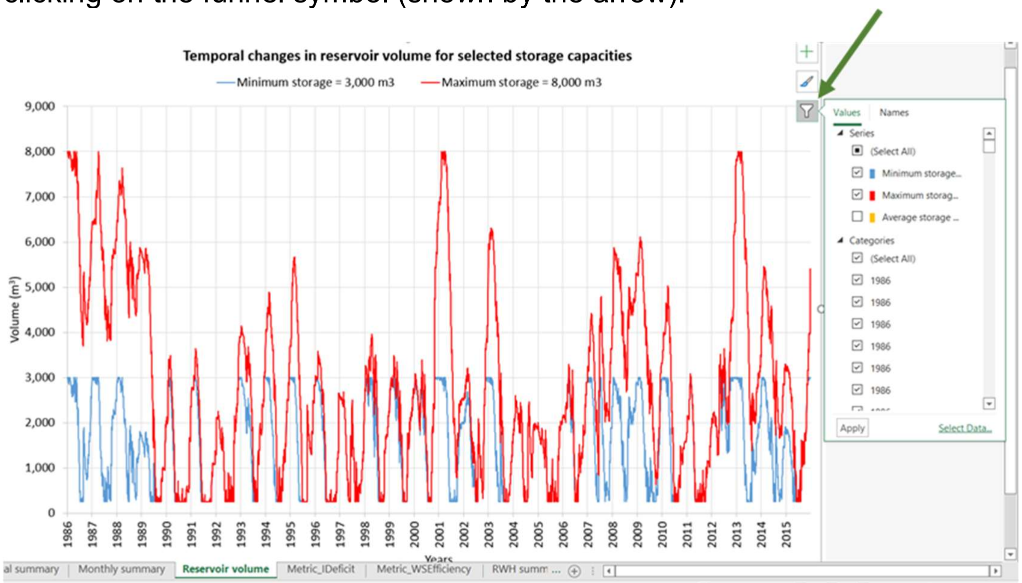
Volume of overflow, representing potentially harvestable rainwater runoff that cannot be collected due to insufficient storage capacity in the reservoir (**mid blue**)

Volume of harvested runoff that enters the reservoir (**pale blue**).

In this example, the RWH system (**light green**)is able to meet almost all irrigation demand until May, when the use of the alternative water source (**dark green**)increases, peaking in July. The reservoir capacity is sufficient to store all potentially harvestable runoff between May and October, but overflows (**mid blue**) between November and April due to a combination of insufficient storage capacity and low irrigation demands.

RWH analysis: Reservoir storage

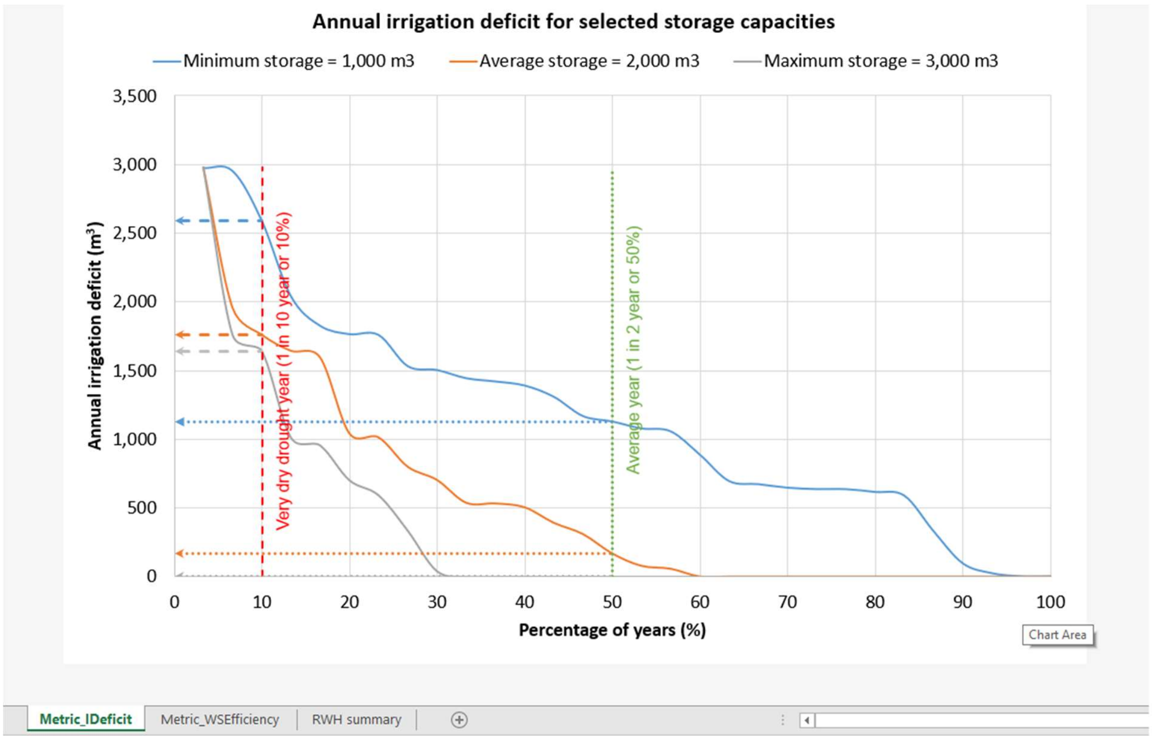
The third summary shows daily outputs of reservoir volume for the 30-year period (1986-2015). The graph can show the outputs for one or more reservoir storage capacities by clicking on the funnel symbol (shown by the arrow).



In this example, the reservoir storage is shown for the minimum (**blue line**) and maximum (**red line**) storage capacities. With the minimum storage capacity, the reservoir refills in the winter in most, but not all, years. However, the maximum storage capacity (**blue line**) is unable to re-fill in most years, showing that the rainwater harvesting area is insufficient to utilise the reservoir storage. Neither reservoir volume drops to zero because of the requirement to maintain the (default) 48 hours of emergency water supply in case of supply interruptions

RWH analysis: Irrigation deficit (m^3)

Based on the data provided in the Site data entry sheet, the RWH tool produces outputs for two key performance indicators. The first is the irrigation deficit (m^3), defined as the gross irrigation demand that is not met due to rainfall uncertainty and insufficient water available in the RWH storage reservoir. An example output for this irrigation deficit metric is shown in the panel below, together with an explanation on how to interpret the data.



This figure shows the cumulative probability (percentage of years) for the annual irrigation deficit metric based on 30 years of historical weather data, for three reservoir capacities (1,000, 2,000 and 3,000 m^3). The minimum and maximum capacities were defined on the Site data entry sheet.

For a given reservoir capacity, the annual probability of an irrigation deficit can be identified. For example, for a 1,000 m^3 reservoir, the figure above provides a **green dotted line** at 50% (or 1 in 2 year) probability that there will be an annual irrigation deficit (shortage of water) of at least 1,200 m^3 shown by **blue dotted arrow**. For the larger (2,000 m^3) reservoir, the annual deficit would be at least 200 m^3 shown by **orange dotted arrow**.

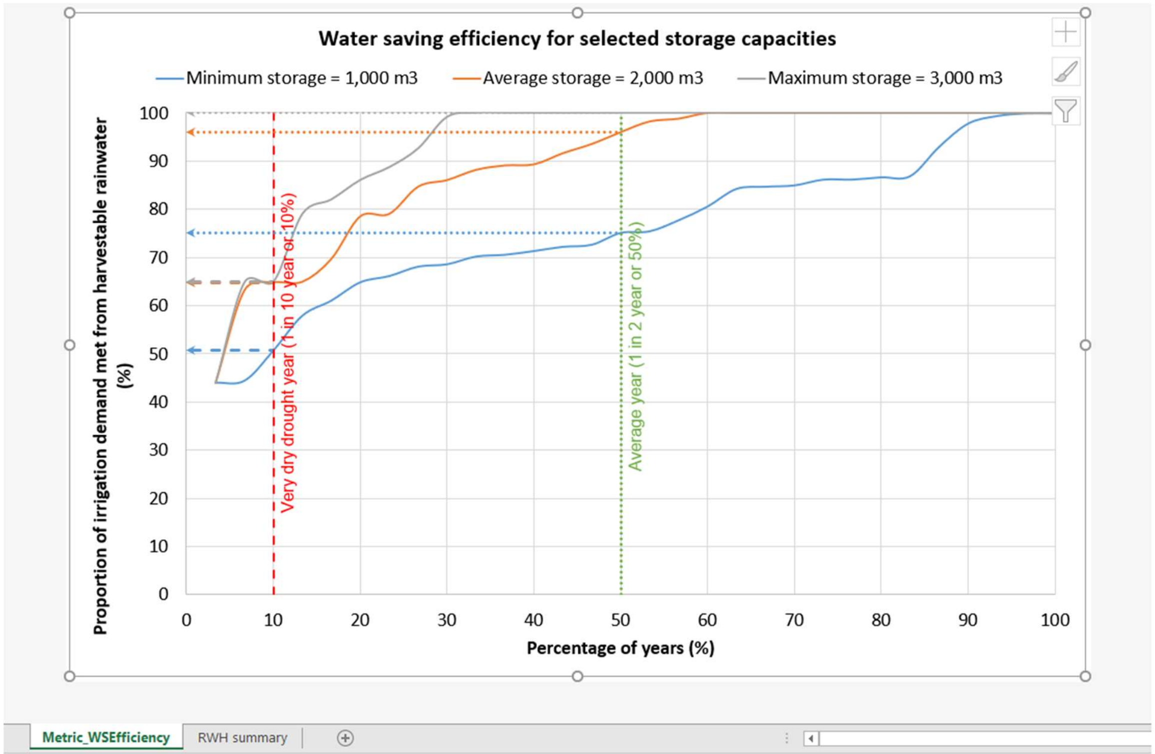
The figure also provides the equivalent data for a more extreme drought year which would be relevant for RWH system or irrigation design purposes. This is shown as the **red dashed line** at the 10% probability level (or 1 in 10 year). For the largest reservoir considered here (3,000 m^3) there would still be an irrigation deficit of at least 1600 m^3, as shown by the **grey dashed arrow**. So even the maximum storage reservoir in this example would be inadequate to meet gross irrigation demand, and a larger reservoir would be needed to reduce or remove any irrigation deficit.

The tool can be used to identify the optimum storage capacity to maximize the use of rainwater, eliminate any irrigation deficit and minimise the reliance (and cost) on an alternative water source to meet irrigation demand.

RWH analysis: Water saving efficiency

The RWH tool also produces a second key performance indicator termed *water saving efficiency* (%). This is defined as the total amount of water supplied from the RWH system as a percentage of the total amount of irrigation water required.

An example output for the water saving efficiency (%) metric is shown in the panel below, together with an explanation on how to interpret the data.



This figure shows the relationship between the percentage of irrigation demand met from the harvestable rainwater (%) and the percentage of years (%). As with the irrigation deficit metric, the data are based on 30 years historical weather and for three reservoir capacities.

For a given reservoir capacity and probability (percentage of years), the water saving efficiency can be identified. For example, for a 1,000 m^3 reservoir, on average (50% of years) the water saving efficiency is around 75%. For the largest (3,000 m^3) reservoir, on average the water saving efficiency is 100%.

However, in very dry drought years, the reliability or water saving efficiency declines, even for the largest reservoir.

In 10% of years, or a 1 in 10-year drought event, the water saving efficiency for the RWH system with the largest (3,000 m^3) reservoir drops to 65%, and for the smallest (1,000 m^3) reservoir the efficiency is nearer to 50%.

This metric is therefore useful in understanding the trade-offs between the size of the reservoir storage, the reliability of the RWH system to meet crop irrigation demand, and the cost to augment supplies with an alternative water source.

RWH analysis: Summary

It is important for a business to critically evaluate the irrigation and water resource implications and economic viability of any potential investment in a RWH system. The final sheet in the RWH tool therefore provides a detailed summary of outputs from the RWH tool, including information on irrigation demand, statistics relating to different reservoir storage capacities, and the two performance metrics. Data on the costs for augmenting any irrigation deficit with water from an alternative source of supply are also provided.

A typical output for the RWH summary is shown below. It contains 3 main blocks of information derived from the model.

Summary RWH model output				
Protected cropping area (ha)	3	ha		
Cropped area (ha)	2.25	ha		
Rainwater harvesting area	2.25	ha		
	mm	m^3		
Average annual Rainfall	628	18,848		
Average annual Reference evapotranspiration (ETo)	529	15,868		
Average annual crop evapotranspiration (ETc)	472	14,148		
Maximum daily irrigation need	6	129		
Maximum ETc	5	112		
Average annual net irrigation	354	10,611		
Average annual leaching requirement	53	1,592		
Average annual Gross irrigation	407	12,203		
Peak irrigation demand (two days)	9	258		
Average annual harvestable rainfall	455	10,227		
Minimum reservoir capacity (m^3)		3,000		
	mm	m^3	%	£
Tank capacity	100	3,000		
Usable storage	91	2,742		
Average annual harvested rainfall	396	8,907		
Average year irrigation deficit	97	2,922		4,002
Very dry year irrigation deficit	223	6,693		9,169
Driest year irrigation deficit	240	7,210		9,878
Average year rainwater saving efficiency			77	
Dry year rainwater saving efficiency			50	
Driest year rainwater saving efficiency			46	
Average reservoir capacity (m^3)		5,500		
	mm	m^3	%	£
Tank capacity	183	5,500		
Usable storage	175	5,242		
Average annual harvested rainfall	439	9868		
Average year irrigation deficit	81	2,435		3,336
Very dry year irrigation deficit	174	5,207		7,133
Driest year irrigation deficit	208	6,252		8,565
Average year rainwater saving efficiency			81	
Dry year rainwater saving efficiency			59	
Driest year rainwater saving efficiency			51	
Maximum reservoir capacity (m^3)		8,000		
	mm	m^3	%	£
Tank capacity	267	8,000		
Usable storage	258	7,742		
Average annual harvested rainfall	448	10,088		
Average year irrigation deficit	73	2,205		3,020
Very dry year irrigation deficit	174	5,207		7,133
Driest year irrigation deficit	208	6,252		8,565
Average year rainwater saving efficiency			81	
Dry year rainwater saving efficiency			59	
Driest year rainwater saving efficiency			51	

RWH storage evaluation

		Selected storage capacities (m^3)		
RWH performance metric	Rainfall year	3,000	5,500	8,000
Irrigation deficit (m^3): Gross irrigation water demand not met due the rainfall variability and insufficient available reservoir storage	Average year	2,922	2,435	2,205
	Very dry year	6,693	5,207	5,207
	Driest year	7,210	6,252	6,252
Water saving efficiency (%): Ratio of the total amount of water supplied from the RWH to the total amount of water demand	Average year	77	81	81
	Very dry year	50	59	59
	Driest year	46	51	51

Notes: The green coloured cells are used to highlight the lower irrigation deficit and higher water saving efficiency and red coloured cells are used to highlight the higher irrigation deficit and lower water saving efficiency achieved for each selected storage capacity, respectively.

Useful summary details on rainfall and ET_o for your farm location, seasonal crop evapotranspiration, leaching requirements and irrigation demand are shown in the top left (white) panel. Values in mm and m^3 are provided.

For each reservoir storage capacity summary statistics are provided on the usable storage and the performance metrics (irrigation deficit and water saving efficiency) for an average, very dry (1 in 10 year) and the driest year. Costs (£) of an alternative annual water supply to offset the irrigation deficit are also provided.

The most important statistics are summarised on the right-hand panel. For each reservoir capacity, data the two performance metrics (irrigation deficit and water saving efficiency) for each weather year (average, very dry and driest) are provided. Colour coding is used to help the user identify the optimum RWH storge-reliability combination.

Acknowledgement

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Disclaimer

The RWH tool and supporting guidance manual are provided for information only. Cranfield University and Kent County Council provide no express or implied warranty as to the quality, fitness for purpose, accuracy or sufficiency of the tool and guidance. The tool and its outputs should be interpreted with caution and you should seek professional advice if you plan to use the outputs to inform investment decisions in a RWH system. No liability shall be accepted by Cranfield University or Kent County Council for any direct or indirect or consequential loss or damage incurred in connection with the use of the RWH tool.