RainCycle© Advanced

Rainwater Harvesting Hydraulic Simulation and Whole Life Costing Tool v2.0

User Manual

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1.0 Introduction

1.1 System Requirements

Minimum	Recommended
IBM Compatible PC	Intel PII 233Mhz CPU or higher + CD ROM
64Mb RAM	256Mb RAM or greater
12Mb disk space per saved file	12Mb disk space per saved file
Monitor/graphics card capable of displaying 8-bit (256) colours in 800x600 resolution	Monitor/graphics card capable of displaying 16-bit colours in 1024x768 resolution
Windows 98, ME, NT, 2000, XP	Windows 2000, XP
Excel 2000 or above	Excel 2000 or above

1.2 An Overview of Rainwater Harvesting Systems

Rainwater harvesting (RWH) systems are not new. For centuries people have collected and stored rainwater close to where it falls and used it for a number of purposes such as drinking, irrigation, watering livestock and general household use. In most developed countries the wide-spread introduction of centralised water supply systems has meant that rainwater harvesting has largely fallen out of vogue. However, in recent years there has been a renewed enthusiasm for the technique in many countries. Reasons for this renewed interest include:

- The escalating environmental and economic costs of providing water via centralised supply systems.
- Potential cost savings associated with using rainwater in place of metered mains water.
- Benefits of rainwater over mains water for certain end uses e.g. rainwater is preferable to mains water for garden irrigation due to its chemical composition.
- The implied sustainability benefits of collecting and using rainwater give it an added attraction for environmentally-conscious citizens.

However, there are still a number of issues surrounding the use of RWH systems that act as barriers to their wider implementation. The main areas of concern are:

- <u>Uncertainty about future costs</u>. Whilst capital (installation) costs can be predicted with a fair degree of accuracy, long-term costs (such as the potential reduction in water bills and future maintenance costs) are harder to forecast.
- <u>Climate variability</u>. The weather is notoriously hard to predict with any degree of accuracy and so likely rainfall patterns, and therefore the amount of harvested water available at any given time, can be difficult to determine.
- <u>Uncertainty over water demand patterns</u>. Water usage within any given building is likely to vary from day to day and predictions of water demand may have a large margin of error.

These three issues often combine and act as a deterrent to installing a RWH system.

1.3 About RainCycle Advanced©

RainCycle Advanced is a state-of-the-art RWH system assessment tool and is the result of several years of active research in the field of sustainable water management. The function of the application is the hydraulic simulation and whole life costing (construction, operation/maintenance and decommissioning costs) of RWH systems for residential, commercial, industrial and public buildings. It is intended as an aid to decision making and can help to remove some of the uncertainty surrounding water supply/demand fluxes and cost issues as highlighted in section 1.2. The Whole Life Cost (WLC) of a RWH system is modelled alongside the WLC of an equivalent mains-only system, enabling the hydraulic and cost performances of both options to be compared.

RainCycle Advanced is a spreadsheet-based application written for Microsoft Excel™ and requires Excel 2000 (or above) to run.

Within the UK/EU region, the licensed version of the application comes with a CD containing, amongst other things, two Excel files. The file called *RainCycle Advanced v2.0.xls* is the main application file and it is recommended that this be copied to your hard drive. When modelling your own systems, this file can be used as a template and new models should be saved under a different file name. The file called *RainCycle Advanced Tutorial.xls* is a fully working version of the application that contains data relating to the RainCycle Advanced tutorial (see chapter 3).

Assumptions

The application was written primarily for RWH systems that collect, filter and store rainwater runoff from the surface of a catchment (such as a roof) for subsequent non-potable uses (such as toilet flushing, washing machines, garden irrigation and car washing). It is intended for use within the UK although it is sufficiently generic enough to be used in other countries that have comparable water supply systems. The model assumes that a metered mains water supply is available to act as a backup if the rainwater harvesting tank is empty.

Application Scope

Simulations run for a user-definable period of between 2 and 100 years. Any system can be modelled as long as the configuration is the same as that in the application. Catchment size, rainfall patterns, storage tank volume, water demand patterns etc are all user-definable and for all intents and purposes have no upper limits set on their values. Some parameters have a maximum upper value of 9,999,999 but this is large enough to accommodate any feasible system e.g. the maximum storage tank volume that can be simulated is 9,999,999m^3, far larger than any tank would need to be in reality. RainCycle Advanced can be used for both new-build and retro-fit assessment purposes.

Main Features

- Storage tank size optimisation routine: allows for the range of viable tank sizes to be identified early on in the design process.
- Cost savings optimisation routine: enables the whole life cost and hydraulic performance of a range of tank sizes to be compared, allowing the most appropriate tank size to be selected for a more detailed investigation.
- Simulation of the proposed rainwater harvesting system for up to 100 years. Main results are output as: WLC comparison between the modelled rainwater harvesting system and an equivalent mains-only system, percentage of water demand that the proposed system can meet and the pay-back period (in years). Average per-year hydraulic and financial results are also available.
- Ability to take into account all associated costs, such as capital (to-build), maintenance/operating and decommissioning costs.
- Detailed hydraulic and financial simulation results are also available, if required.
- Scenario modelling: allows the user to investigate system variability by manually altering values on a number of key parameters. It is possible to model a total of 1,331 variations for any given design.
- Sensitivity analysis: allows the robustness of the system to be evaluated as well as helping to identify areas for potential improvement.
- Monte Carlo simulation: uses random sampling of probability distributions to automatically assign new values to key parameters and to run thousands of simulations for a given model. Results are output as cumulative probability distribution function graphs which can be used to investigate performance variability and associated risks.
- Automatic report generation for the system under study. No need to copy or export results to another workbook or word processor.
- Comprehensive error-checking routines keep a track of all user-inputs. Any erroneous data entries or changes to key data will be flagged and brought to the user's attention.
- Select from three default currency types ($, € or £) or specify a user-defined currency type.

Limitations

The application is a hydraulic (mass-balance) and whole life costing simulation tool and does not model water quality. However, it does allow for the inclusion of a UV unit and will take into account the associated operating and maintenance costs. It should be noted that for most well-built and well-maintained non-potable RWH systems, the provision of adequate particle filtration prior to harvested water use is considered to be sufficient protection against water-borne infections. In rare cases where there is deemed to be an elevated risk of infection, or just for peace of mind, the use of a UV unit in addition to particle filtration is considered sufficient to virtually eliminate any risk of infection.

The application is not designed to explicitly model greywater systems (that is, systems that collect and reuse lightly contaminated water from appliances such as baths and showers, wash basins etc but *not* ‘black’ water, such as water from toilets and dishwashers). However, the Additional Inputs module can be used to represent the daily input of greywater, or any other source of additional water, into the storage tank. It should be noted that greywater systems are technically more complex and there are also further safety concerns e.g. potential increase in risk of infection compared to purely rainwater collection systems. The application does not model any greywater specific parameters, such as chemical dosing or micro-filtration, and so the Additional Inputs feature should be used with caution.

Inputting Data

Cells that can accept user inputs are coloured white. It is not possible to enter data into any other cells, or to alter any of the formulas in the application. Most cells requiring user input have also been data validated and will only accept values within a given range or that meet certain criteria e.g. within the range 0-9,999,999 or whole numbers only.

1.4 Data Requirements

Tables 1.1 and 1.2 show the information that is required in order to carry out a detailed assessment. Note that in the User Manual all financial costs are denoted in £ (pounds sterling) but that the application has the option of using different currency types.

Table 1.1 - Hydraulic data required for a detailed assessment

Parameter	Units	Comments
Rainfall data	mm/day	High, expected and low daily rainfall data for one whole year. Use actual rainfall statistics or generate rainfall profiles using the Rainfall Data Wizards
Catchment surface area	m^2	Plan area of catchment surface
Catchment surface runoff coefficients	-	High, expected and low catchment runoff coefficients (advice on suitable values is provided in chapter 2)
First-flush volume	litres	Some RWH systems divert the initial ‘first-flush’ of effective runoff away from the storage tank. This is in order to prevent any surface contaminants (e.g. dust, leafs and twigs) from washing into the tank.
Rainwater filter coefficients	-	High, expected and low rainwater filter coefficients (advice on suitable values is provided in chapter 2)
Additional water inputs	l/day	High, expected and low additional water inputs i.e. water entering the storage tank in addition to runoff from the catchment surface, such as greywater
Storage tank volume	m^3	Storage capacity available in the modelled tank
Drain-down intervals	days	Estimation of the frequency and date of tank drain-downs e.g. to facilitate maintenance/repair work
Power rating of pump	kW	None
Pumping capacity of pump	l/min	None
UV unit power rating	W	None
Water demand profiles	m^3/day	High, expected and low daily water demand values. Use actual statistics or generate a demand pattern using the Water Demand Wizards (see also appendix 2 for additional information)

Table 1.2 - Financial data required for detailed assessment

Parameter	Units	Comments
Capital costs	£	High, expected and low 'to-build' costs for the modelled system inc. purchase and installation of all components + VAT
Maintenance/operation schedules and associated costs	£	Estimated maintenance costs and required frequency of maintenance activities
Decommission costs	£	High, expected and low costs to remove and dispose/recycle system components
Discount rates	%	High, expected and low discount rates to relate future costs back to their Present Value (PV)
Electricity costs	p/kWhr	High, expected and low costs of electricity
Mains water costs	£/m^3	High, expected and low costs of mains water
Disposal costs	£/m^3	High, expected and low costs of water disposal. *Note that this is in addition to any sewerage costs* e.g. trade effluent charges. In most cases these will not apply and so there will be zero disposal cost

Advice on where parameter data can be obtained is given in chapter 2 along with some generic values in case site-specific information is not available.

Note that where a range of values can be used it is not strictly necessary to have data available for all the ranges. However, using only one set of values restricts the ability to analyse system variability and also means that a sensitivity analysis and/or Monte Carlo simulation cannot be performed. If you try to run either of them under these circumstances you will simply get an error message.

The amount of data required for an assessment will depend largely on how detailed the assessment is intended to be. A basic study will require less information than shown in tables 1.1 and 1.2 and might only require one value for each parameter.

1.5 Main Components of the RainCycle Advanced© Application

1.5.1 Navigating Around RainCycle Advanced

When the application first loads you will be presented with the "System Map" screen. This is used primarily to navigate around the program. To access a module from here, simply click the relevant module box (see section 1.5.2 for more details). When viewing an actual module, navigation buttons will be displayed in the top right-hand corner of the screen. There will always be at least one button labelled "System Map". Click this to return to the System Map screen. Other buttons will be available if a particular module has further sub-modules. Figure 1.1 shows the navigation buttons located in the Water Demand module.

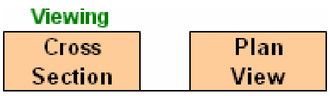
Figure 1.1 – Navigation buttons located in the Water Demand module

All sub-modules contain at least two buttons. One labelled “System Map” and one labelled “Back”. The latter returns the user to the main module from which the sub-module is accessed.

<u>Navigation Tabs</u>

A number of modules contain “Navigation Tabs” (see figure 1.2 for an example). These are used to select different sections of the module. To select the required section, click on the relevant navigation tab. The word ‘Viewing’ will appear in green text over the last tab clicked, indicating which section is currently selected.

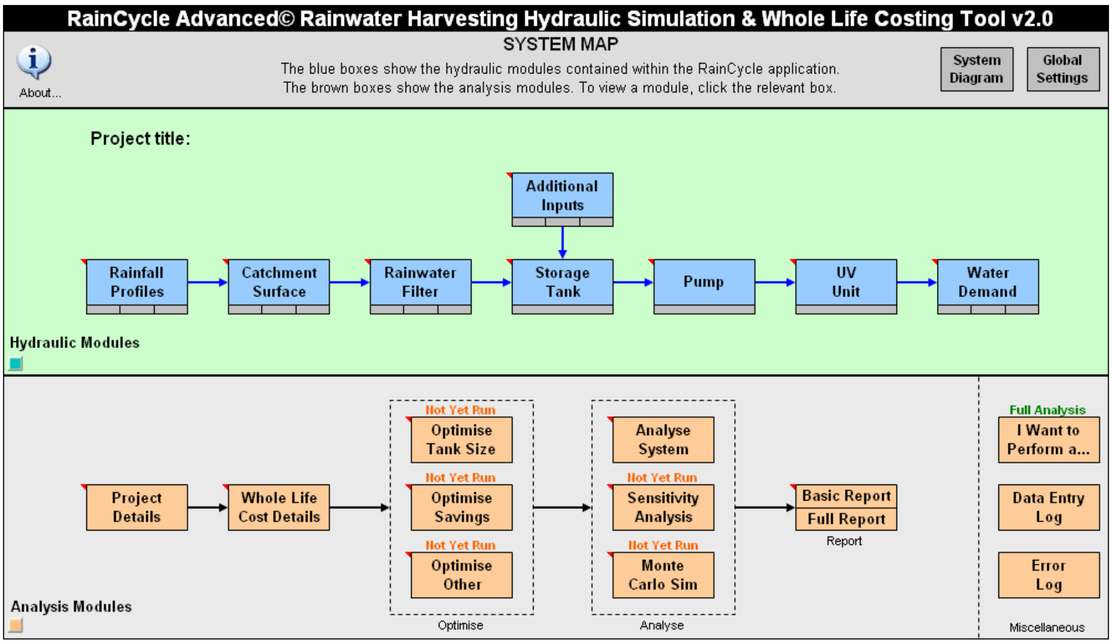
Figure 1.2 – System Diagram navigation tabs



1.5.2 System Map

The *System Map* is the main navigation screen from which the rest of the application can be accessed. The System Map is divided into three sections (see figure 1.3). The top section is the title bar and also contains buttons on the right-hand side for the System Diagram and Global Settings modules. The middle section shows a flow diagram of RainCycle’s hydraulic modules and these represent the stages that are involved in the collection, storage and use of the harvested rainwater. The bottom section shows the analysis modules. To select a module, click the corresponding box.

Figure 1.3 – System Map screen



Located beneath each of the hydraulic module boxes is a series of grey rectangles (either one or three, depending on the actual module). These are the module Status Boxes and they indicate the current level of information within each module by changing colour. Grey means that the key data fields in a given module are either blank or contain only zero values. Green means that the key data fields contain an entry other than zero. Red would indicate an input error e.g. text has been inadvertently entered into a numerical field. The Status Boxes allow the user to see at a glance which hydraulic modules contain data and which do not.

The Rainfall Profiles, Catchment Surface, Rainwater Filter, Additional Inputs and Water Demand modules each have 3 rectangles. This is because each of these modules contains input fields for various Variable Parameters (parameters that can have more than one set of values, more on this later). The rectangle on the left represents the current status of the corresponding above average/high variable parameter, the middle rectangle the average/expected variable parameter and the one on the right-hand side the below average/low variable parameter. The same colour codes apply as for the single rectangles i.e. grey = blank or zero values only, green = value other than zero, red = data input error.

The Status Boxes can be turned off if required (see section 1.5.4: Global Settings module).

On the left-hand side of the screen are two small toggle buttons (one blue in the hydraulic modules section, one brown in the analysis modules section). Toggling these on/off hides or shows the sub-module boxes. When shown, these can be clicked on to open the various sub-modules. The toggle buttons are de-selected by default in order to simplify the appearance of the screen.

1.5.3 System Diagram

The System Diagram consists of a series of diagrammatic sketches that show the various components found in a typical RWH system, with the components that RainCycle explicitly models shown in blue (see figure 1.4). Cross section and plan view diagrams are available. If the "Show volumes" checkbox is ticked then a number of text boxes will appear showing the water volumes per year associated with each hydraulic component. All volumes are reported in m^3/yr.

Each blue-coloured component has a corresponding module which can be selected by clicking on the relevant component in the diagram.

1.5.4 Global Settings

Use this module to configure a range of global (application-wide) settings. The following parameters can be configured:

Enable Status Boxes

On the System Map, turns the Status Boxes on/off (see section 1.5.2 for more details).

Set Analysis Runtime

Set the number of years the analysis is to run for. Range: 2-100 years.

Select RWH System Cost Items

Use this feature to include/remove any of the financial items associated with the RWH system. If an item is removed, all costs incurred by that item will be given a value of zero throughout the analysis. By default, all the items are included.

Select Currency

Select the required currency type from the drop-down list. Three pre-defined currencies are available: dollars ($), euros (€) and pound sterling (£). There is also a fourth option labelled "Other". This allows for the use of currencies other than the three pre-defined ones. If "Other" is selected, further on-screen instructions on how to proceed will appear.

The selected currency will be applied throughout the application (all hydraulic and analysis modules, as well as both system reports)

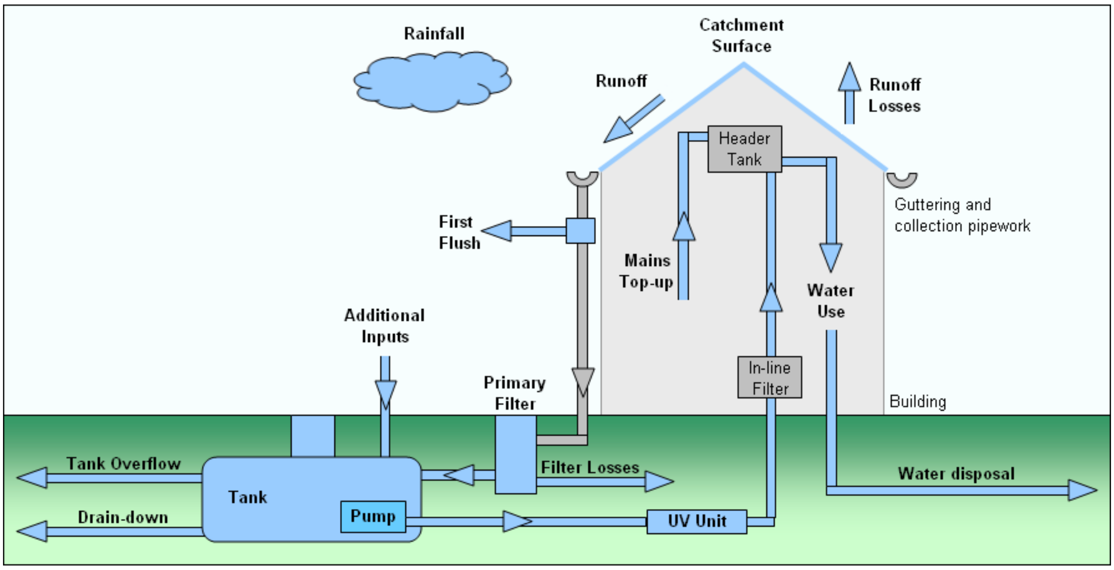
Select 1st Jan Day

Allows the user to select what day of the week the 1st of January should correspond to (the default is Monday). This feature can be useful when determining water demand patterns and it is necessary to assume that the 1st of January falls on a specific day.

1.5.5 Overview of Hydraulic Modules

A diagrammatic sketch of RainCycle's hydraulic model is shown in figure 1.4 (note that this is the same as the cross sectional diagram found on the System Diagram screen). On the diagram, each component coloured blue has a corresponding hydraulic module.

Figure 1.4 – Diagrammatic sketch showing RainCycle's hydraulic model components
(components explicitly modelled by RainCycle are coloured blue)



Rainfall Profiles

Input daily rainfall data in mm/day for one year. There are three rainfall data ranges available: above average, average and below average. Either select a monthly average rainfall profile from the data sets provided, manually input data cell-by-cell, import (copy/paste) data from another source or use the Rainfall Wizards to create rainfall profiles.

Catchment Surface

Records details of the catchment surface (the area that will be used to collect rainwater for the proposed system). Input the catchment *plan* area, up to three runoff coefficients (high, expected and low) and the first-flush volume (if any).

Rainwater Filter

Input up to three rainwater filter coefficients (high, expected and low).

Storage Tank

Records details of the rainwater storage tank. Input tank *storage* volume, specify the mains top-up location (storage tank or in-building header tank) and set drain-down intervals (if any).

Additional Inputs

This module allows any water inputs other than rainwater to be taken into account. There are three data fields available: above average, average and below average input. Either manually input data cell-by-cell, import (copy/paste) data from another source or use the Input Wizards. *Please note: if you intend to input greywater (e.g. water from baths/sinks) into the storage* *tank then there are added safety concerns that need to be taken into account. Refer back to section 1.3 (Limitations) for further details*.

Pump

Record details of the water pump. Input power rating and pumping capacity.

UV Unit

Record details of the UV unit. Input UV unit power rating and daily operating time.

Water Demand

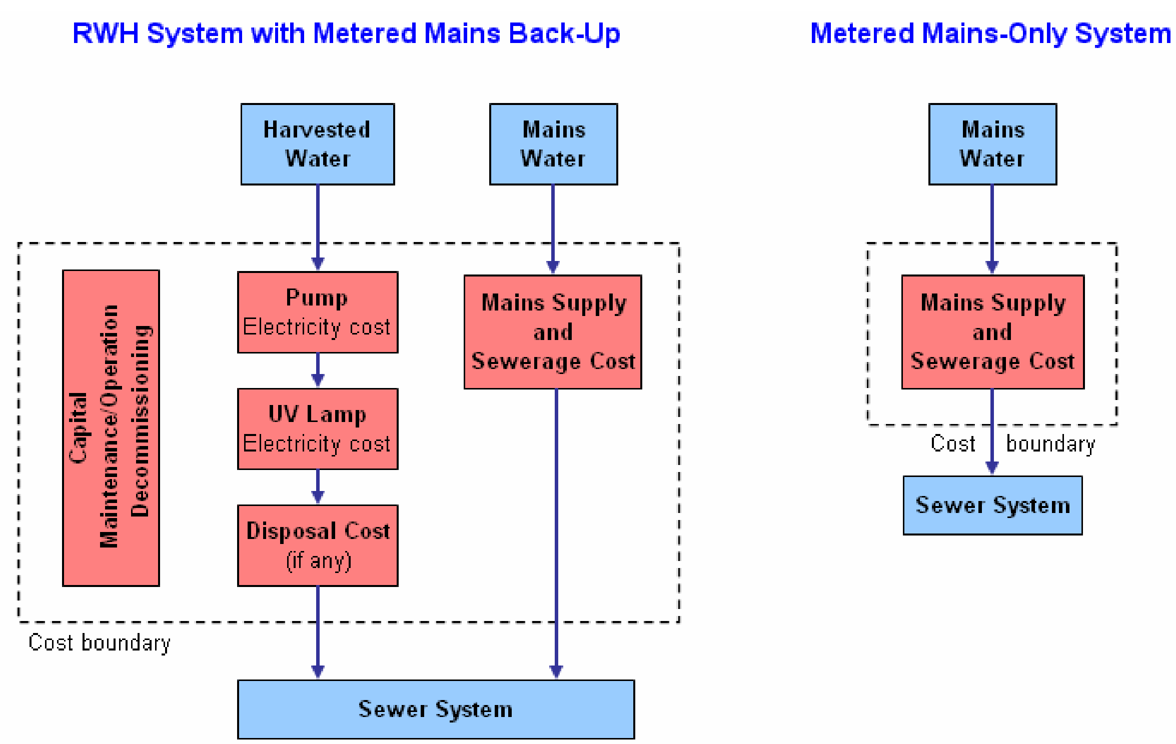
Input daily water demand data in m^3/day for one year. There are three data ranges available: above average, average and below average demand. Either manually input data cell-by-cell, import (copy/paste) data from another source or use one of the Water Demand Wizards.

This module also has two sub-modules. The Demand Calculator is there to help estimate the water demand for a range of building types and associated water uses. The Data Sets sub-module relates to the Water Demand Wizards and allows these to be customised to some extent.

1.5.6 Overview of Analysis Modules

A diagrammatic sketch of RainCycle's financial model is shown in figure 1.5. On the diagram, the components explicitly modelled are coloured red.

Figure 1.5 – Diagrammatic sketch showing RainCycle's financial model components



The cost boundary in both flow charts indicates the limit of RainCycle's financial analysis. Anything outside this boundary (shown in blue) is not modelled whilst everything inside the boundary (shown in red) is, or more precisely there is the *option* to model these items. Cost items that are not required can be deselected in the Global Settings module. Alternatively, it is always possible to input zero costs for any of the red items, effectively removing them from the analysis e.g. if there is no UV unit it can be eliminated from the assessment by entering zero values for the UV parameters, thereby giving zero running costs.

Note that the diagram for the RWH system shows that the cost of any mains top-up required is an integral part of the financial analysis. By default, RainCycle does not look at the cost of the RWH system in isolation. This is because the key factor in the financial analysis is the *overall* costs/savings and it is important to include the value of any mains top-up required during times of short-fall. If this is not done then it would appear as though any mains water were being supplied for free and this would lead to some very strange results, such as the RWH system performing better financially the less water it delivered (since any short-fall would be made up by mains water with zero supply cost).

Project Details

Enter company and client details relating to the system under study. A number of fields are available:

- Date (default is the current Windows date. Can be overwritten if required)
- Company Details
- Client Details
- Project Details (project title and project stage)
- Project Description

The above items are replicated in the system reports. There is another field below these labelled "Project Notes". Any text entered here is for user information only and will not be replicated in the project reports. (It may be necessary to scroll down to see this section, depending on the screen resolution setting).

Whole Life Cost Details

The Whole Life Cost (WLC) Details module is where the life-cycle cost data for the system under study is stored. Information relating to capital, maintenance/operating and decommissioning costs are recorded here.

Optimise Tank Size

Before an in-depth analysis is conducted, the Optimise Tank Size module can be used to give an estimate of the percentage of demand that a range of tank sizes can meet for the catchment under study. This will help to narrow down the range of tank sizes that can provide a good balance between tank size (i.e. cost) and system performance (i.e. the amount of harvested rainwater supplied).

The Optimise Tank Size feature also contains a sub-module called “Alternative Tank Sizing Methods”, which can be accessed by clicking the corresponding navigation button located in the top right-hand corner of the screen. This sub-module contains a number of routines which are equivalent to the more common ‘rule-of-thumb’ techniques for storage tank sizing. These can be used in place of RainCycle’s own tank sizing method, although this is not recommended for larger commercial/industrial systems as they are likely to give inaccurate results.

Optimise Savings

Once a suitable range of tank sizes has been determined, obtain capital and operating costs for each and then use the Optimise Savings module to determine which tank size will give the best long-term performance.

Optimise Other

Optimise a number of other parameters for the system under study. In version 2.0 only Catchment Size Optimisation is available. Additional routines are planned for future upgrades.

Analyse System

The Analyse System module is where the proposed RWH system can be manually evaluated. Rather than having to accept only one set of results based on one set of parameter values, it is possible to assess multiple “what-if” scenarios and determine how the system performs under a range of different circumstances. Results from modelled scenarios are presented in two ways 1) long-term results show how the system performs over the whole selected analysis period (in years) as compared to a mains-only system 2) short-term results show how the system performs on a yearly basis as compared to a mains-only system.

There are 7 *fixed* parameters that can have 1 value each and 11 *variable* parameters with a range of 3 possible values each, meaning that a total of 11^3 = 1,331 variations of any given system can be simulated.

The Analyse System screen contains a number of sub-modules which can be accessed by clicking the navigation buttons located in the top right-hand corner of the screen.

- Per-Year Results: shows the *average* per year financial results for the system under study. For both the RWH and equivalent mains-only systems under study, all long-term costs are added together and then divided by the analysis runtime (in years). This gives the average running cost per year for both systems. From this the average yearly savings (if any) are calculated.

- Detailed Results: detailed hydraulic and financial information relating to the system under study is available in this sub-module.

Sensitivity Analysis

Assesses each of the variable parameters in turn and determines how reliant system performance is on each of these parameters. This is particularly useful for identifying areas of potential improvement or areas of uncertainty/high-risk.

Monte Carlo Simulation

Uses random sampling of probability distributions to automatically assign new values to key parameters and to run thousands of simulations for a given model. Results are output as cumulative probability distribution function graphs that can be used to investigate performance variability and associated risks.

Basic Report / Full Report

Once an analysis has been completed, two system reports are automatically generated. The Basic Report should be selected if only one set of values was used for the variable parameters, as it assumes that this was the case. The full report should be used if a detailed analysis was conducted in which the RWH system was assessed using multiple values on the variable parameters. The full report also contains any scenario modelling, sensitivity analysis and Monte Carlo simulation results, which the basic report does not.

Both reports can be printed by using Excel's built-in print function.

I Want to Perform a…

Opens a dialog box which allows the appearance of the application to be changed to suit the type of analysis being performed. For the selected option, any modules that are not required are greyed out on the System Map screen. For modules that are essential but contain sections that are not required (e.g. high/low data entry fields), the relevant fields are either greyed out or hidden from view entirely.

Data Entry Log

This module provides a summary of the key parameters and associated values.

Error Log

The Error Log keeps track of potential data input errors. Most of the application has been protected and the majority of the cells that can accept user-inputs have been data validated so that erroneous entries cannot be made. However, there are a number of data ranges where this was not feasible and so an error log has been provided to track the data in these cells and to report any possible data entry errors. Table 1.3 shows the tracked ranges and highlights the circumstances in which errors will be reported.

Table 1.3 – Error Log details and possible reasons for errors

Item	Possible Reasons for Error
Rainfall Profiles module: above average, average and below average daily rainfall depths (mm/day) for one whole year	Negative number and/or text entry in rainfall depth column
Additional Inputs module: above average, average and below average daily inputs (litres/day) for one whole year	Negative number and/or text entry in input column
Water Demand module: above average, average and below average water demand (m^3/day) for one whole year	Negative number and/or text entry in demand column
Whole Life Cost Details module: maintenance activities and associated costs table	Maintenance frequency of active item(s) contains an error
Monte Carlo Simulation: maintenance probabilities sub-module	Maintenance frequency of active item(s) contains an error

If any errors are detected then the Error Log box on the System Map screen will turn red. Also on the System Map, if the Status Boxes are enabled (see section 1.5.2) then the corresponding box will turn red.

Data Tracking

The application also keeps track of certain data ranges and informs the user if changes have been made to them. This is important for the Optimise Tank Size, Optimise Savings, Optimise Other, Sensitivity Analysis and Monte Carlo Simulation modules as the current results in these depend on what data was in the application when the corresponding analysis was last run. If entries that these routines use as part of their calculations are changed and they are not re-run to take into account these changes, then the results being displayed will not represent the current data. If these changes are intended to be permanent, then the corresponding analysis should be re-run in order to ensure that the results reflect the data in the spreadsheet.

If changes are detected, they are reported in two ways.

- On the System Map screen, the word “Changes” will appear in red text above the analysis modules that are affected (not necessarily where the change is located)
- In the analysis modules that are affected by the changes, a warning message will appear (white text on a red background) informing the user that changes have occurred and recommending that the analysis be re-run.

It should be noted that genuine data entry *errors* (not just changes to data *values*) can also trigger this response. If any of the aforementioned modules are reporting changes *and* the Error Log module box has turned red (indicating that a problem has been detected), then the errors should be corrected before any analysis is re-run as this may solve the problem without the need to take any further action.

Getting Help

Most of the modules have helpful comments inserted in appropriate cells. These are denoted by a small red triangle located in the upper right-hand corner of the cell and can be viewed by hovering the mouse pointer over the appropriate cell for a few seconds. Information boxes are also provided in several modules (denoted by the Windows information icon, an 'i' in a speech bubble). If the information icon appears in the top left-hand corner of the screen and has the words 'More info' next to it, this means that the icon is clickable and will produce a pop-up dialog box which contains further information.

1.6 Learning to Use RainCycle Advanced©

RainCycle Advanced is a large and detailed application and as such it may take some time to learn how to use all of the features. To help users get to grips with the software, the instruction manual contains a number of tutorials (see chapter 3) that go through a full analysis of a rainwater harvesting system, utilising all of the features that the program offers. The tutorials are based on an actual RWH system case study and show how to apply the software to a real-life situation.

The recommended 'learning process' is as follows:

1. Read chapters 1 and 2 of the manual.
2. Go through the tutorials (chapter 3) to get a feel for the software (highly recommended – you will learn more by *doing* than you will simply by *reading*).
3. Read the rest of the manual (chapter 4 and appendices 1-6).
4. Carry out a basic analysis of your own (can be based on an actual system or a fictitious one) e.g. just use average/expected values for all parameters and don't perform any scenario modelling, sensitivity analysis or Monte Carlo simulation.
5. When you feel confident in using the basic features, begin to perform more detailed analyses. Aim to get to the stage where you can confidently use all of the available features quickly and efficiently.
6. If you get stuck, refer back to the manual or use the Information dialog boxes/comments scattered throughout the program. See also appendix 3: Trouble Shooting and Frequently Asked Questions.

RainCycle Advanced also comes with a program called RainCycle Standard©. This is a simplified version of RainCycle and it may be easier to use this program first in order to learn the basic techniques before moving on to the full application.

1.7 License Details and Software Upgrades

When the application first loads, you will be presented with the License Details dialog box. You may only use the application if you are the named licensee or are an employee of the company/organisation that the license pertains to. To view the license details at any other time, go to the System Map screen and click the information icon located in the top left-hand corner of the screen.

Licenses are sold in batches. One license entitles the license holder to install RainCycle on one machine e.g. if 5 licenses are purchased then RainCycle can be installed on 5 machines in total. If further licenses are required then SUD Solutions should be contacted to discuss specific requirements.

Purchasing a software license also entitles the license holder to free after-sales support which includes upgrades and patches of RainCycle version 2 for life. Customers will be informed by email when updates/patches are available for download.

1.8 Contacting Us

For free information/advice regarding any of our products, to report bugs or to suggest improvements, please direct your emails to:

support@sudsolutions.com

Alternatively write to us at the following address:

SUD Solutions
PO Box 104
LEEDS
LS13 9AA
West Yorkshire
United Kingdom

We will endeavour to deal with any enquiries as quickly as possible.

Note: if your query is regarding the use of one of our products then we strongly advise you to refer to the instruction manual before contacting us. We are happy to answer any questions that you may have but reading the relevant part of the instruction manual can often provide the information you seek in less time than contacting our support team would.

1.9 Copyright Notice

You may only use RainCycle v2 if you are the registered license holder, or you are an employee of the registered license holder. Licences can be obtained from SUD Solutions. Visit: www.SUDSolutions.com for further details.

Windows and Excel are registered trademarks of the Microsoft Corporation.

1.10 Legal Information

SUD Solutions accept no responsibility and exclude all liability whatsoever in respect of any person's use and/or reliance upon any data generated by the RainCycle© application.

1.11 Further Reading

Users who are not familiar with rainwater harvesting systems and who wish to know more are advised to consult the following documents:

CIRIA C539 (2001). *Rainwater and Greywater Use in Buildings – Best Practice Guide*. CIRIA. London, UK.

CIRIA Report 80 (2001). *Project Report 80. Rainwater and Greywater Use in Buildings – Decision Making for Water Conservation*. CIRIA. London, UK.

CIRIA Report C626 (2004). *Model Agreements for Rainwater and Greywater Use Systems*. CIRIA. London, UK.

WRAS [Water Regulations Advisory Scheme] (1999). *Information and Guidance Note. Reclaimed Water Systems: Information about Installing, Modifying or Maintaining Reclaimed Water Systems*. August 1999. No 9-02-04. Issue 1.

Note that the above resources relate to the use of rainwater harvesting systems within the UK. For countries outside the UK, refer to the relevant best practice guidance and legislation regarding the use of harvested rainwater for that specific country.

Internet Resources

An overview of rainwater harvesting systems and some freely downloadable files are available from the UK Environment Agency's website:

http://www.environment-agency.gov.uk/subjects/waterres/286587/511050/?lang=_e

2.0 Performing an Analysis with RainCycle Advanced©

2.1 Detailed Design of Rainwater Harvesting Systems

Whilst it is possible to design a complete RWH system from scratch and to construct it from separately purchased components, a more common approach is to employ the services of a company that specialises in the supply of complete off-the-shelf systems. There are a number of such companies currently operating in the UK and some of these can be found in the Members Section of the UK Rainwater Harvesting Association's (UKRHA) website: http://www.ukrha.org. (Please note this link is provided for information only. SUD Solutions does not endorse any of the content this website contains).

Unless you have the necessary technical expertise to design and construct a RWH system then asking for advice from a specialist company is a sensible approach. Many of them offer free advice and can supply much of the basic information needed to carry out an analysis using RainCycle e.g. technical data, up-to-date capital and maintenance costs, engineering drawings and specifications and so on.

2.2 Information and Advice on Performing an Analysis

The recommended approach is as follows:

- Read through the rest of this chapter in order to gain a better understanding of the information required in order to carry out your own assessment.
- Collect as much of the required information as possible. This chapter also provides some generic data for a number of parameters which can be used in the absence of site-specific information.
- If not all the required data can be found, or if what can be acquired is not satisfactory, then a RWH company/supplier should be contacted. Most will ask for some basic information about the intended system and in return should be able to supply capital cost data, maintenance requirements/schedules, water demand estimates, technical advice, engineering drawings etc.
- Enter the details into RainCycle and analyse the proposed system. Note that the level of complexity of the analysis is entirely up to the user.
- Assess the results. If the results are not acceptable, then either reject the proposed system or redesign it (e.g. increase catchment area, increase water usage). If the results are acceptable, implement the proposed design.
- If the system is to be implemented, a RWH company/supplier should again be contacted and arrangements made for delivery of the components. Installation should always be performed by a competent person, such as a qualified engineer/plumber.

2.3 The RainCycle Advanced© Analysis Process

There is no universally agreed 'right' way to design and analyse a rainwater harvesting system but there are a sequence of logical steps that, if followed, will increase the likelihood of creating a successful design. This section contains a number of flow-charts which lead the user through these steps (see figures 2.1 - 2.4) and divides the design and analysis process into 4 distinct steps:

- Step 1: determine range of suitable tank sizes.
- Step 2: determine cost savings of tanks from (1) and choose optimum size
- Step 3: assemble data required for detailed analysis.
- Step 4: perform detailed analysis and critically examine results.

As well as the flow-charts, advice is given on how to generate/obtain the required data. Generic figures are also provided for a number of parameters; these can be used in the absence of site-specific information.

Goal & Scope Definition

Before an analysis is conducted, it is advisable to make explicit the goals (aims and objectives) and scope (system conditions, boundaries & limits) of the proposed system. Important issues to address could include:

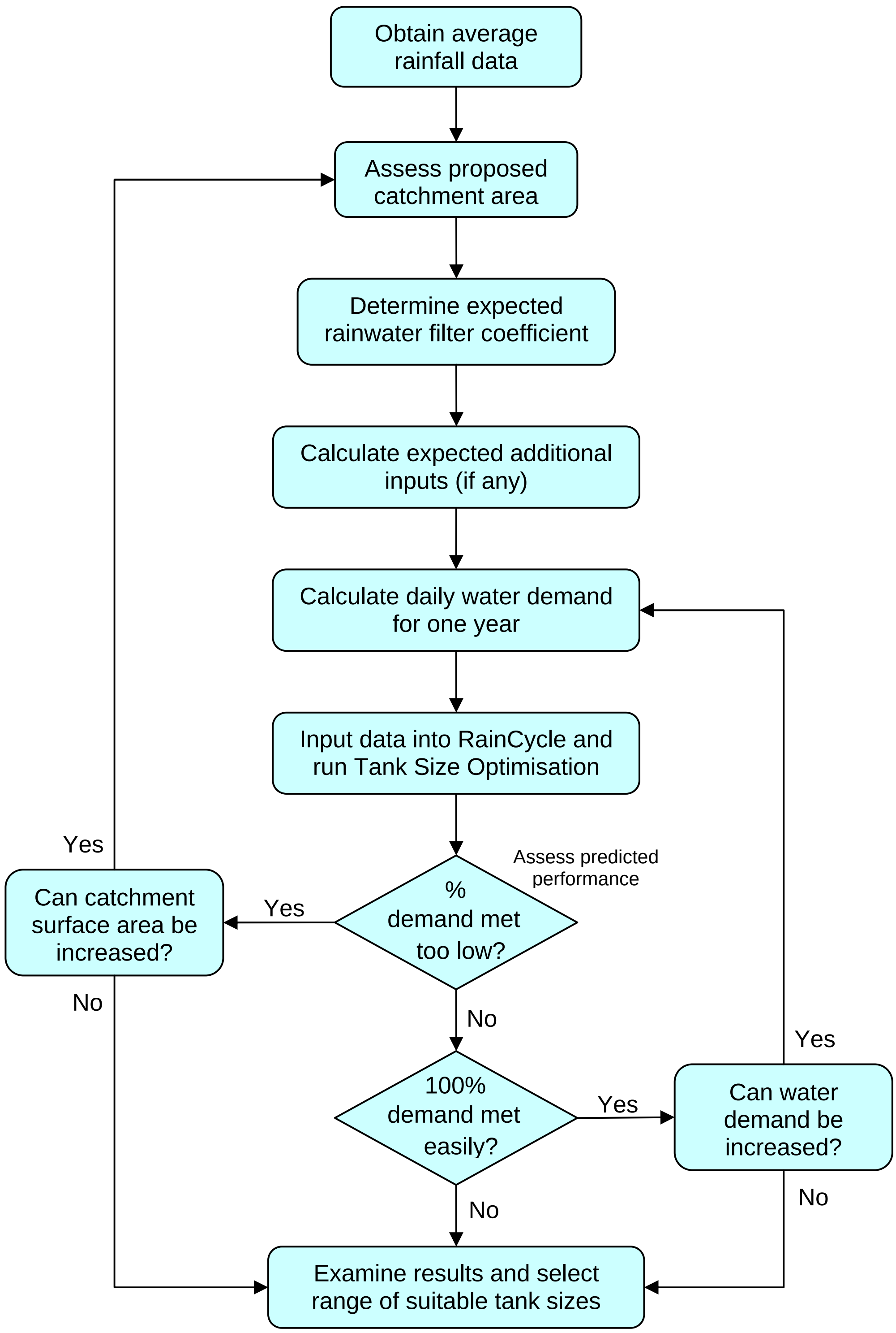
- What are the intended uses for the harvested rainwater? Will they be non-potable only or does the water require treatment to potable standards?
- Does the system require a UV treatment unit?
- What level of risk/responsibility is likely to be acceptable?
- What are the reasons for wanting a RWH system? Are they purely financial (potential water bill savings) or is there an environmental element? E.g. conservation of water resources.
- Is a short pay-back time important, or is a longer period acceptable?

Essentially it is important to have a clear idea in mind as to what the rainwater harvesting system is intended to do, the minimum level of performance that will be deemed satisfactory and what level of risk is likely to be acceptable (e.g. financial risk).

The hydraulic and financial criteria that any RWH system will have to meet are entirely up to the individual or organisation considering the system. RainCycle Advanced is ideally suited to determining whether or not these criteria can be met, and under what circumstances.

2.3.1 Step 1: Determine range of suitable tank sizes

Figure 2.1 - Step 1 flowchart



2.3.2 Obtain Average Rainfall Data

The amount of rainfall available for collection is one of the key factors in the success (or otherwise) of any rainwater harvesting system. It is therefore important that the rainfall data used is as accurate as possible. Since rainfall patterns vary from region to region, the rainfall data should relate to the catchment area under study.

Generally speaking there are 3 types of rainfall data available. In terms of decreasing accuracy, they are:

1. Daily rainfall statistics (mm/day)
2. Monthly rainfall statistics (mm/month)
3. Yearly total rainfall (mm/year)

Daily rainfall statistics are not always available for every location in the UK and even if they are they can be difficult to locate. Monthly rainfall statistics are easier to obtain and data sets for average monthly rainfall depths in 10 UK regions have been included with RainCycle. More data is available from the UK Met. Office (see: http://www.met-office.gov.uk).

Finally, in the absence of more accurate information, a single yearly average figure can be used. Note that this is not recommended since it does not take into account seasonal variations in rainfall patterns.

2.3.3 Assess Proposed Catchment Area

Determine Catchment Plan Area

The catchment area is the surface (usually a roof) that will collect and channel rainwater to the storage tank. It is necessary to calculate the plan area of the catchment surface i.e. the length multiplied by the width if one were looking down on the catchment from directly above. Roof areas for domestic dwellings vary from building to building but they generally fall somewhere between 50 and 100m^2. Catchment areas for other building types (e.g. commercial or industrial) are likely to be site-specific and so will have to be determined on a case-by-case basis.

Determine Expected Runoff Coefficient

The runoff coefficient determines how much water will flow from the catchment surface when it rains and how much is lost. Not all of the rain landing on a roof (or other surfaces) will end up in the pipe collection system. Surface wetting (the fraction of rainfall that 'sticks' to a surface when it starts to rain), evaporation, ponding in depressions and the type of surface material all effect the level of effective runoff. Table 2.1 shows typical runoff coefficients for various roof types as well as some other common surfaces.

Table 2.1 – Typical runoff coefficients for various surface types

	Coefficients		
Surface Type	**High**	**Expected**	**Low**
Pitched roof tiles	0.90	0.85	0.75
Flat roof with smooth surface	0.60	0.55	0.50
Flat roof with gravel or thin turf (<150mm)	0.50	0.45	0.40
Asphalt or similar surface	0.90	0.85	0.80
Block pavements with wide joints	0.70	0.60	0.50
Gravel roads and driveways	0.30	0.20	0.15

Note: a coefficient of 0 = 0% runoff, a coefficient of 1 = 100% runoff

2.3.4 Determine Expected Rainwater Filter Coefficient

Filter coefficients are best obtained from manufacturers or suppliers of rainwater harvesting components. In the absence of more specific data, a coefficient of 0.90 can be used.

2.3.5 Calculate Average Additional Inputs (if any)

Refers to storage tank inputs other than rainwater, such as greywater from baths and showers. Note that this would imply the use of a dedicated greywater system, which should be designed by a qualified engineer. It is not recommended that greywater be stored in a system that is intended for rainwater only. If the system under investigation is designed to only accept rainwater then greywater should *not* be input into the storage tank.

2.3.6 Calculate Average Daily Water Demand for One Year

If recorded water usage data for the building under study exists then it should be possible to calculate the daily water demand from this (appendix 3 contains further information which will be of assistance). RainCycle itself comes with a Demand Calculator sub-module that can be used to create a daily demand estimate. Alternatively, estimates can usually be obtained from RWH system suppliers.

It is strongly recommended that a site-specific water demand profile be determined. This is especially true for commercial, industrial and public premises since water usage here can vary widely from building to building. It is not advisable to use 'average' figures or data obtained from a different building. This is less of an issue for domestic dwellings since water usage per person tends to be more consistent, although site-specific data should still be obtained if possible. The Demand Calculator sub-module, which is accessible from the Water Demand screen, can be used to calculate demand values for domestic dwellings as well as commercial/industrial premises

Important Note The water demand estimate should *only* refer to that which is intended to be met by the rainwater harvesting system e.g. toilet flushing and washing machine supply. Do *not* include demand which is to be met by other means such as drinking water which is to be supplied only from the mains.

2.3.7 Input Data into RainCycle and Run Tank Size Optimisation Analysis

Input the catchment surface area and first-flush volume (if any) as well as average/expected values for the rainfall, runoff coefficient, filter coefficient, additional inputs and water demand. Once the data has been input correctly, go to the 'Optimise Tank Size' module, enter a sensible figure in the *Max. Tank Size to Simulate* field (e.g. 20m^3 for a domestic system) and click the Analyse button.

2.3.8 Examine Results and Select Range of Suitable Tank Sizes

Once the optimisation analysis is complete, examine the results table and corresponding graph, both of which are located in the bottom half of the screen. If the system performance is satisfactory then select an appropriate range of tank sizes. Aim to select tank sizes that meet a respectable amount of the water demand but that aren't excessively large, in order to keep capital costs to a minimum. For domestic systems, tanks are usually available in sizes of 1-6m^3 so try and choose sizes that fall within this range. There is a wider range of sizes available for commercial and industrial systems and the most appropriate ones need to be selected with some care. For instance, if a 30m^3 tank can meet 85% of demand and a 15m^3 tank can meet 80% then the best choice would be the 15m^3 tank. The extra 5% that the 30m^3 tank could supply is unlikely to compensate for its increased cost over the smaller tank.

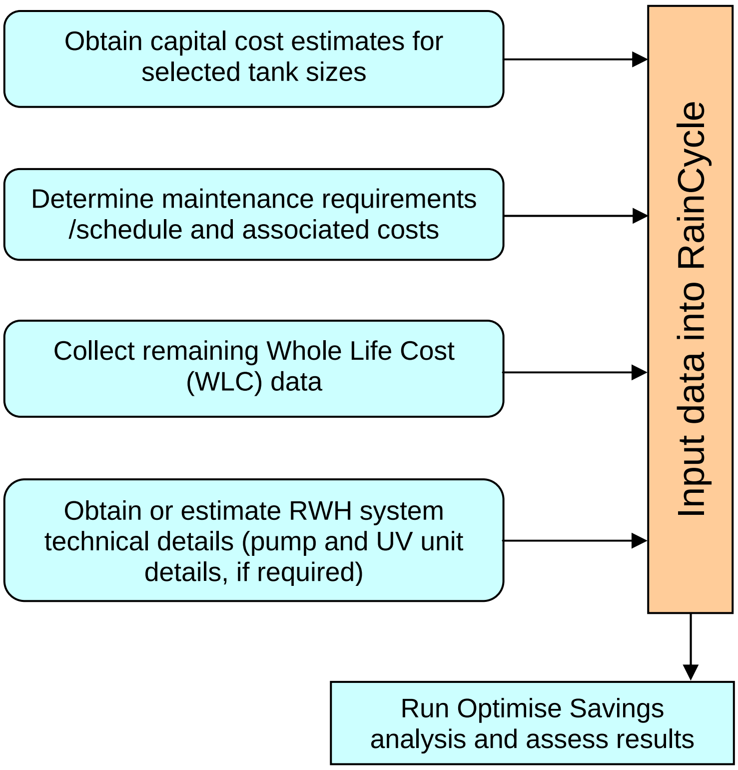
All in all, try and choose the smallest tank sizes that can meet an acceptable amount of the water demand. Any commercial/industrial RWH system that can supply 70-100% of the required volume is generally considered to provide a good level of service. Domestic systems tend to perform less well than this because of their inherent small catchment sizes (usually a house roof) and in general they can satisfy between 20-50% of non-potable demand.

Alternative Methods for Sizing Rainwater Tanks

The Optimise Tank Size module also contains a sub-module called Alternative Tank Sizing Methods, which can be accessed by clicking the corresponding navigation button located in the top right-hand corner of the screen. This sub-module contains a number of routines which are equivalent to the more common 'rule-of-thumb' techniques for storage tank sizing. These can be used in place of RainCycle's own tank sizing method, although this is not recommended for larger commercial/industrial systems as they are likely to give inaccurate results.

2.3.9 Step 2: Determine cost savings of selected tank sizes from Step 1 and choose optimum size

Figure 2.2 - Step 2 Flowchart



2.3.10 Obtain Capital Cost Estimates for Selected Tank Sizes

Capital/Installation Costs

Capital costs are best obtained from RWH system suppliers. In the absence of more accurate data, the figures in tables 2.2 and 2.3 can be used as a rough guide for capital costs (prices are for the UK, 2005). Costs for commercial/industrial systems tend to be highly site-specific; there tends to be less variation with domestic systems, although accurate up-to-date figures should still be sought. See also appendix 6 for a Bill of Quantities for a typical storage tank.

Table 2.2 – Typical capital costs for commercial/industrial RWH systems

Description	Component Costs (£)	Installation Costs (£)	Total Capital Cost (£)
$10m^3$ tank , no pump (gravity driven), up to $1000m^2$ catchment area	3,300	3,000	6,300
$10m^3$ tank with pump, up to $1000m^2$ catchment area	4,000	4,000	8,000
$20m^3$ tank , no pump, up to $3000m^2$ catchment area	6,000	6,000	12,000
$20m^3$ tank with pump, up to $3000m^2$ catchment area	6,500	6,000	12,500
$30m^3$ tank, no pump, up to $10,000m^2$ catchment area	10,000	10,000	20,000
$30m^3$ tank with pump, up to $10,000m^2$ catchment area	11,000	10,000	21,000

UK prices, 2005

Table 2.3 – Typical capital costs for domestic RHW systems

Tank size (m^3)	Component Costs (£)	Installation Costs (£)	Total Capital Cost (£)
1.5	1,600	1,000	2,600
2.4	1,700	1,000	2,700
3.0	1,800	1,000	2,800
4.0	1,900	1,000	2,900
5.0	2,000	1,000	3,000
6.0	2,300	1,000	3,300
6.5	2,700	1,000	3,700

UK prices, 2005

UV disinfection units cost in the region of £1200. Generally speaking, installation costs for domestic systems are approximately £1000.

2.3.11 Determine Maintenance Requirements/Schedule and Associated Costs

Maintenance schedules for commercial/industrial systems tend to be site-specific and requirements are best discussed with suppliers. Maintenance of domestic systems is normally straightforward and modern systems are designed with ease of maintenance in mind. It should be possible for the homeowner to carry out basic maintenance tasks by themselves e.g. cleaning the leaf filter. More complicated tasks, such as checking or replacing the pump, should only be carried out by a qualified individual. Table 2.4 shows a typical maintenance schedule for a domestic set-up.

Table 2.4 – Typical maintenance schedule for domestic RWH systems

Item	Activity	Frequency	Comments
Self-cleaning and/or coarse (i.e. leaf) filters	Check and clean	Every 3-6 months	Check during autumn/spring seasons
Roofs and gutters	Check and clean	1-2 times per year	Ensure adequate safety precautions are taken when cleaning roofs and gutters
Pump	Check operation and wiring	Once per year	Should only be carried out by a qualified electrician
UV unit	Check operation and replace lamp	1-2 times per year	Should only be carried out by a qualified electrician

Tip: as part of a detailed analysis, a range of frequencies for each maintenance activity could be simulated.

Maintenance Costs

Maintenance costs will vary depending on whether the owner is able/willing to perform some of the activities themselves (in which case the labour cost is essentially zero), the type of maintenance required, cost of replacement items and the frequency of activities. Again, RWH system suppliers are able to provide an accurate description of the type of maintenance that a specific system requires. Some offer their own maintenance service and this is often a good way to reduce future uncertainty over costs since many just charge a flat fee to carry out the agreed works.

Approximate costs for typical maintenance activities are presented in table 2.5.

Table 2 .5 – Approximate costs for typical maintenance activities

Item	Activity	Frequency	Cost per Activity (£)
External maintenance contract	Typically consists of one visit per year to check system performance, repair/replace pump and clean filters	As agreed with contractor (usually once per year)	£250/year
Clean roofs and gutters	Sweep/wash roof surface to clear any debris. Unblock and clean guttering	1-2 times per year	£100/visit
Clean filters	Check and clean all filters	2-4 times per year	£50/visit
Pump	Check operation and wiring. Repair/replace as necessary	1 per year. Typical replacement frequency is 5-7 years	£500 to replace
UV lamp	Replace UV lamp	1-2 times per year (once is typical)	£60/visit

2.3.12 Collect Remaining Whole Life Cost (WLC) Data

Operating Costs

Operating costs in RainCycle consist of the following items:

- Discount rate. Effects the relative cost of future financial expenditures.
- Electricity costs (to run the pump and UV unit, if applicable).
- Mains water costs
- Water disposal cost (if any).
- Cost of consumables.

Discount Rate

Future costs are heavily dependent on the selected discount rate. The discount rate is explained in appendix 1. However, the concept is not always easy to grasp and the term itself is not widely known outside of accounting circles. It should be noted that in order to use RainCycle it is not strictly necessary to take the discount rate into account. It is likely to be most applicable to businesses or large organisations that need to undertake proper financial accounting of future cash flows. It may not be particularly useful to people simply wanting a small domestic system. If this is the case, all discount rate data entry fields can be set to zero, resulting in all future costs simply being reported back at their *equivalent current price*s i.e. what those items would cost if they had to be paid for right now.

The UK Treasury currently recommends a discount rate of 3.5%. Unless this advice changes, the Expected Discount Rate should be entered as 3.5%.

Electricity Costs

Electricity prices can be obtained by contacting the local utility or from a recent electricity bill. The average price of electricity in the UK is currently about 7 pence per kilowatt hour (7p/kWhr).

Mains Water Costs

Mains supply and sewerage costs for all primary UK Water Authorities have been included in the application. Alternatively, prices can be obtained by contacting the local water utility or from a recent water bill. Note that, in the UK, the future cost of mains water is likely to increase significantly faster than the rate of inflation. Prices in some areas are predicted to rise by as much as 18% over the next five years. This is partly due to increasing water scarcity (especially in the south and southeast), increasing energy costs and more stringent environmental legislation, such as the EU Water Framework Directive (WFD).

Water Disposal Cost

Most water utilities do not charge to dispose of used rainwater to their sewer system, although this may change in the future if RWH systems become more widespread. Some large commercial/industrial sites may be subject to trade effluent charges which need to be taken into account. In most cases there will be no disposal charge and so a value of zero can be entered for the water disposal cost parameter.

Cost of Consumables

Some rainwater harvesting systems employ items that need regular replacement, such as filter cartridges or disinfectant modules. These can be taken into account by using the maintenance schedule planner located in the Whole Life Cost Details module.

2.3.13 Decommissioning Costs

Decommissioning a RWH system consists of removing/excavating the component parts and disposing of them, most likely to a landfill site. The Decommissioning Cost has its own field in the WLC Details module. Decommissioning is assumed to occur at the end of the analysis runtime period (as specified in the Global Settings module).

Decommissioning is unlikely to be an issue for domestic systems since the major components (e.g. tank, pipework) are likely to last as long as the building itself. Commercial/industrial systems may need decommissioning if the site undergoes a change of usage and the building needs to be demolished. In this case, the system is likely to be removed as part of a larger contract to clear the site and this should be taken into account when estimating the decommissioning cost. The cost of removal may be negligible when compared to the overall cost of site clearance. In this case it may be acceptable to assume a zero decommissioning cost.

2.3.14 Obtain or Estimate RWH System Technical Details

Obtain or Estimate Pump Details

Pump details are best obtained from suppliers/manufactures. In the absence of case-specific details, use the figures in table 2.6 that most closely match the proposed pump.

Table 2.6 – Generic pump data

Pump power rating (kW)	Pumping capacity (l/min at given height)		
	10m	20m	30m
0.8	60	50	30
1.0	63	55	45
1.2	65	58	52
1.4	67	60	55

Note: if power rating is in horse power, to convert to kW multiply by 0.746

Obtain or Estimate UV Unit Details

UV unit details are best obtained from suppliers/manufactures. In the absence of case-specific details, use the figures in table 2.7 that most closely match the proposed UV unit. Note that the unit must be capable of processing the maximum anticipated flow of water passing through the device (in most cases given by the pump's capacity).

Table 2.7 – Generic UV unit data

Max. flow rate (l/min)	20	45	80	140	220
Power rating (W)	35	50	60	90	100

Run Optimise Savings Routine and Assess Results

The Optimise Savings routine works by running a separate analysis for all the tank sizes input into the Tank Sizes to Analyse table. The values shown in the Summary of Required Parameters table will be applied to each tank size.

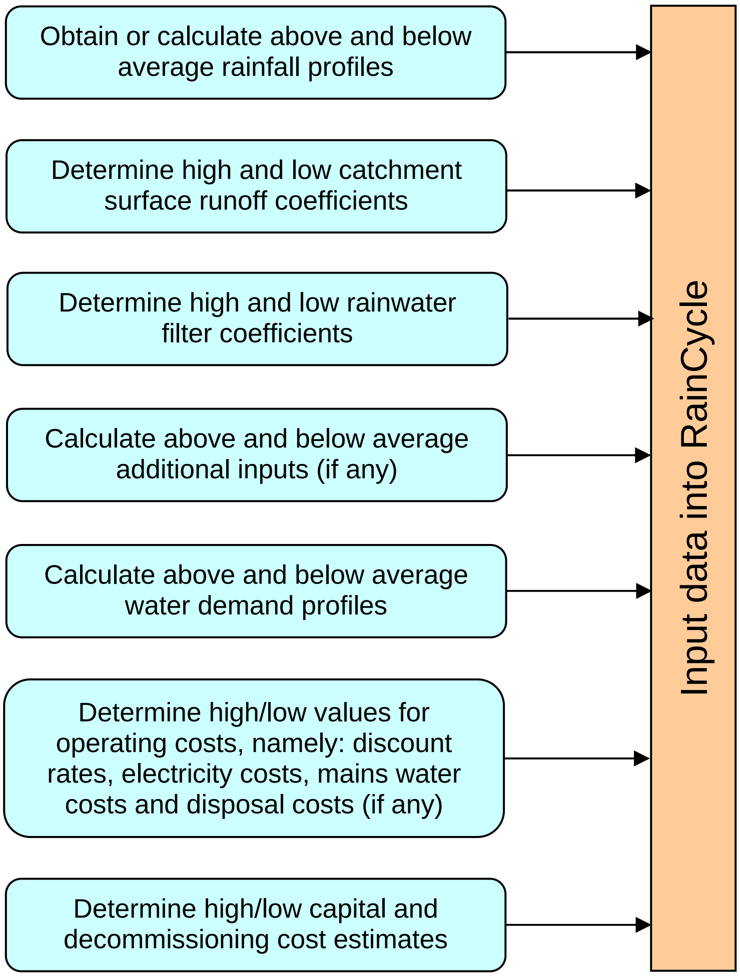
To run the analysis, click the green Analyse button. The analysis will only take a few seconds to run and the results will be displayed in the Latest Simulation Results table. Results can be sorted by using the Results Sort Criteria. Simply select the required option from the drop-down list.

Assess Results

How the results are interpreted will depend on the purpose of the RWH system. If the main goal is financial savings then the tank size with the greatest long-term savings is likely to be the best choice. Or perhaps the system with the quickest pay-back period may be more desirable, or the one that can meet the highest percentage of demand. Alternatively the tank size that has the best overall performance may be preferable – one that gives good results for long-term savings, pay-back period and percentage of demand met. Ultimately some human judgement needs to be applied when deciding which tank size to take forward to step 3.

2.3.15 Step 3: Assemble data required for detailed analysis

Figure 2.3 - Step 3 flowchart



2.3.16 Obtain or Calculate Above and Below Average Rainfall Data

It may be possible to obtain above/below average rainfall statistics from the Met. Office, although these figures are generally harder to find than average rainfall statistics and are unlikely to be available for every region of the UK. If site-specific data cannot be found then above/below average rainfall figures can be generated by adding/subtracting a given percentage from the average rainfall intensities. This is currently the recommended method for taking into account the potential future effects of climate change when modelling drainage infrastructure. A common approach is to add/subtract 25% from the average figures.

2.3.17 Determine High/Low Catchment Runoff Coefficients

Match the type of catchment surface against the closest entry from table 2.1 (page 22) and use the corresponding high/low coefficient values.

2.3.18 Determine High/Low Rainwater Filter Coefficients

High/low filter coefficients are best obtained from RWH system suppliers, although they generally only supply the expected figure. In the absence of more specific data, use 0.92 and 0.85 for the high and low values respectively.

2.3.19 Calculate Above and Below Average Additional Inputs (if any)

Above/below average additional inputs are best calculated on a case-by-case basis. In the absence of more specific data, take the expected additional input figure and add/subtract 20% from this value to obtain the above/below average figures respectively.

2.3.20 Determine Above and Below Average Daily Water Demand for One Year

If recorded water use data is available for the building under study then this can be used to establish realistic above/below average water demand patterns. Alternatively, base the figures on the estimate for average water demand. Add/subtract a given amount from the average value e.g. in chapter 3 (the tutorial) 20% is added/subtracted from the average demand for each day. Whichever method is used, ensure sure that the figures are realistic. Ideally the above average figure should represent the highest most likely to occur in practice demand and the below average figure the lowest most likely to occur in practice.

2.3.21 Determine High/Low Operating Costs

Discount Rate

The UK Treasury is currently recommending a discount rate of 3.5%. The previous rate was 6% and so this is an acceptable figure for the High Discount Rate value. It is unlikely to fall below 2% at any point in the future and so this value can be used for the Low Discount Rate.

Electricity Costs

The cost of electricity in the UK has been steadily increasing for some years at a rate significantly above that of inflation (in early 2005 it rose almost 10% a month for two months in a row). All sources indicate the rise in prices is likely to continue and so future electricity costs could be considerably higher than at present. For the high cost of electricity, increasing the expected price by between 15-25% would not be unrealistic. Regarding the low cost, prices are unlikely to fall in the future to the same degree as they are rising now. Reducing the expected cost by 5-10% at the most would be a realistic ‘best-case’ scenario under the present circumstances.

Mains Water Costs

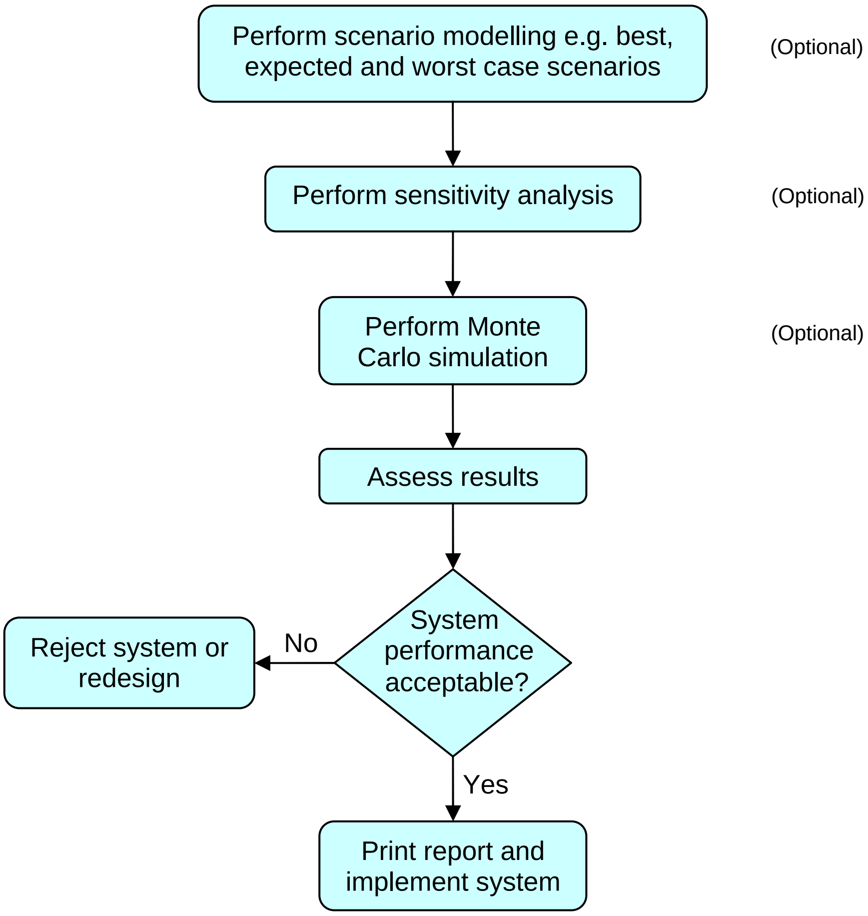
As with electricity prices, mains water costs in the UK have been rising steadily. Future price increases of up to 18% are predicted in some areas (mainly the south and south-east) and so adding 18% to the expected cost of mains water for the high price would not be unrealistic. For the low price, subtract no more than 5-10% from the expected value.

2.3.22 Determine High/Low Capital and Decommissioning Costs

If sufficient information, knowledge and experience is available then it may be feasible to calculate site-specific high/low values for capital and decommissioning costs. A more common approach is to take the expected values and add/subtract a percentage in order to give the upper and lower boundaries e.g. take the expected capital cost and add 10% to give the high cost and subtract 10% to give the low cost. The former method is likely to be more accurate but the latter is more commonly used.

2.3.23 Step 4: Perform detailed analysis

Figure 2.4 - Step 4 flowchart



2.3.24 Perform Scenario Modelling

All the information necessary to carry out a detailed analysis has now been collected and input into the RainCycle application. It is now possible to perform a detailed assessment of the system under study.

As many or as few scenarios can be modelled as are deemed necessary, although it is recommended that at least 3 be investigated – those being the best, expected and worst case i.e. all variable parameters set to their best value from the point of view of the RWH system, then average/expected and then worst. This will define the upper and lower boundaries for system performance and also set the mid-point (the expected scenario).

There are several important points to keep in mind:

- RainCycle has a maximum of 6 data 'slots' in which to store simulation summary results. To access these, click the button in the Analyse System module labelled "Record Results". If more than 6 simulations are run then it will be necessary to write down any additional results.
- The long-term analysis results and the average per-year results contained within the Analyse System module relate to the *current* figures selected for the simulation. This also applies to the automatically generated reports - the detailed graphs and results refer to the current system.
- If any of the system's key parameters are changed (e.g. water demand patterns, cost data etc) then the results being displayed for the *current* system will automatically update with the new figures. However, any results recorded in data slots 1-6 will not automatically update. It will be necessary to re-run the previous simulations and to update the slots with the latest results summaries.

2.3.25 Perform Sensitivity Analysis

Performing a sensitivity analysis is optional but recommended as it will highlight which variable parameters have a potentially significant impact on system performance and which have little. A sensitivity analysis can only be conducted once all the necessary data has been input into RainCycle. That is, all fixed parameters to have one value each and all variable parameters to have 3 sets of values each (above average/high, average/expected and below average/low).

It is possible to model a system using only 1 value for each variable parameter (e.g. all average/expected) but it will not be possible to run a sensitivity analysis. If an attempt to run a sensitivity analysis with incomplete data is made then RainCycle will produce an error message and will not allow the analysis to proceed.

2.3.26 Perform Monte Carlo Simulation

Performing a Monte Carlo simulation is also optional but again is recommended as it will determine not only the range of variation within the system but also the *probability* of that variation and the likelihood of certain conditions being met e.g. that the pay-back time will occur within a given number of years or that the long-term savings will be greater than or equal to a given amount.

A Monte Carlo simulation can only be conducted once all the necessary data has been input into the application. That is, all fixed parameters to have one value each and all variable parameters to have 3 sets of values each (above average/high, average/expected and below average/low). Also, high/low frequencies for maintenance activities and costs are required. A sub-module is provided specifically for this purpose which can be accessed from the main Monte Carlo module.

2.3.27 Assess Results

Whether or not performance is acceptable will depend on the criteria used to judge the RWH system and these will vary from case to case. Potential monetary savings are obviously an important consideration but there are also the implied environmental benefits to take into account and so, even if the system has a long pay-back time or even runs at a loss, it may still be worth implementing from an environmental perspective.

Whilst there is no universal set of criteria with which to judge whether or not a RWH system should be implemented, some common assessment criteria could include:

- Does the system pay for itself within a reasonable timeframe?
- Are the long-term savings significant enough?
- Does it meet an acceptable amount of the expected water demand?
- How robust is the system if conditions vary from those expected? E.g. if rainfall or water demand is less than anticipated.
- What is the probability that the system can achieve the stated goals?

RainCycle Advanced will help to answer the above questions. It assesses both the long- and short-term performance of the proposed RWH system under a wide range of circumstances, determines the optimum tank size, reduces the level of uncertainty and, using sensitivity analysis and Monte Carlo simulation, highlights areas of concern and/or areas for potential improvement. It also reduces the large amount of data produced by the analysis to smaller, more manageable chunks that are easier to understand. However, the decision to implement the system or not ultimately requires a degree of human judgement.

If System Performance is not Deemed Acceptable

In this case, then there are two options to consider:

1. Reject the system outright.
2. Redesign the system so that performance becomes acceptable.

In the second case, there are a number of approaches that may be worth attempting:

- Increase water demand e.g. increase the number of proposed uses.
- Increase the catchment surface area e.g. consider collecting water from areas other than roof surfaces, such as paved areas or car parks. The Optimise Other module can be used to determine what level of demand can be met by a range of catchment sizes.
- Try and reduce costs e.g. cheaper systems may be available elsewhere, or perhaps installation/maintenance costs can be reduced through better design. Is it possible to obtain a grant or to raise more money to fund the system?
- Re-evaluate the performance criteria e.g. the system may perform poorly from a monetary point of view but have the environmental benefits also been taken into account?

If system performance is deemed acceptable, print the report and then implement the project. It may still be possible to make further improvements and so the points highlighted above are worth considering even if the scheme successfully passes the feasibility stage.

2.4 Summary of Parameter Data Sources

Table 2.8 shows a summary of the parameters that are required for a full analysis and some possible sources of information.

Table 2.8 – System parameters and some possible sources of information

Parameter/Item	Sources of Information (in order of preference)*
Rainfall Profiles	Actual site-specific rainfall profiles, obtainable from: The Met. Office; Water Authority; local Environmental Agency office (UK). Monthly average rainfall statistics (UK regional data supplied with RainCycle)
Catchment Surface	*Plan Area*: design/engineering plans of the building; physical measurement; estimate from site inspection
	Runoff Coefficient: design/engineering plans of the buildings combined with guidance in table 2.1; site investigation/observation combined with guidance in table 2.1
Rainwater Filter Coefficient	Manufacturers own technical literature; use 'average' value of 0.90
Additional Inputs (if any)	Actual recorded water usage data from building under study; estimate of water usage for building under study
Daily Water Demand	Actual recorded water demand data from building under study; estimate of water demand for building under study (own estimate or contact RWH supplier)
Capital Costs	Supplier's quote for required system components and quantity surveyor's estimate of installation costs; data from previous similar schemes; average data e.g. from tables 2.2 and 2.3
Maintenance Requirement /Schedules and Associated Costs	Site-specific requirements to be discussed with system supplier and site owner/management company; review latest best practice guidance (e.g. CIRIA manuals, table 2.4); use information from previous schemes with similar characteristics
Operating Costs	*Cost of Electricity*: Local electricity utility; recent electric bill; historic data
	Discount Rate: Determine case-specific discount rate; use latest UK Treasury recommendation (currently 3.5%)
	Cost of Mains Water: Local water utility; recent water bill; historic data. Supply and sewerage costs for primary UK Water Authorities are supplied with RainCycle
	Water Disposal Cost: Local sewerage undertaker; recent water bill/trade effluent charges agreement; historic data
	Cost of Consumables: Suppliers of required items; information from previous schemes with similar requirements
Decommissioning Costs	Quantity surveyors estimate of removal/disposal cost; information from previous schemes with similar characteristics
Obtain or Estimate RWH System Technical Details	*Pump Details*: supplier/manufacturer of pump; generic data from table 2.6
	UV Unit Details: supplier/manufacture of UV equipment; generic data from table 2.7

**In order of preference* relates to the likely accuracy of data from the listed sources i.e. the earlier a source is listed, the more accurate data from that source is likely to be compared to those listed later

2.5 Practicalities of Data Gathering

Whilst in an ideal world it would be easy to obtain all the site-specific information that RainCycle Advanced requires for a detailed analysis, the reality is that this is not always possible. Some information may not be as detailed or as accurate as is desirable, and some may not be available at all. Alternatively, information may exist but is proving difficult to track down. Given that most people have deadlines to meet and numerous responsibilities to attend to, spending large amounts of time gathering data may not be feasible.

However, this does not mean that the RWH assessment process should be abandoned altogether if accurate, site-specific information for all parameters cannot be found. Quite often, average or typical data is available that will suffice in place of more accurate information (this chapter presented a lot of generic figures that can be used in place of site-specific data). Further, it is important to remember that RainCycle is a *model* of a rainwater harvesting system and that, like all models, it is only a representation of reality. Even if the best possible data was used throughout the analysis, it still would not give an answer that was 100% accurate since exact knowledge of the future is unobtainable. This is the reason why scenario modelling, sensitivity analysis and Monte Carlo simulation were included - so that a diverse range of circumstances can be simulated thereby significantly increasing the chances that the *actual* future conditions will be covered within the analysis. These features can go a long way to compensating for a precise lack of knowledge regarding future conditions.

In conclusion, one should aim to get the best data that is available but there is no need to become obsessive about obtaining figures that are accurate to 10 decimal places!

3.0 A Tutorial Guide to Using RainCycle Advanced©

This chapter of the User Manual takes the reader through a number of tutorials that explain in detail how to conduct a full RWH system assessment and how to interpret the results. The tutorials progress in a logical manner and highlight the recommended steps when performing a detailed investigation. Note that when performing your own analysis it is not strictly necessary to follow the steps in the same order, nor to use all of the available features e.g. it may not be relevant to use the Optimise Tank Size module if tank sizes have already been determined, or the level of detail required many not warrant a Monte Carlo simulation. However, the tutorials do highlight all of the available functions and demonstrate how to use them, so it is advisable to work through this chapter as a learning exercise if nothing else.

Performing a full and detailed assessment is a combination of goal & scope definition, data gathering, investigation & analysis, results generation, reflection & discussion and a narrowing down of the available options until the optimal solution is reached. The tutorials assume that we are starting from the very beginning of the process and that a full analysis is required.

A completed version of the tutorials is available - see the supplied Excel file called *RainCycle Advanced Tutorial.xls*. It is suggested that you go through the tutorials using the template version of RainCycle Advanced i.e. the Excel file called *RainCycle Advanced v2.0*. If you save the tutorial at any point, do not save it over the original file. Instead save it under a different file name.

The tutorials are based on an actual RWH system for a UK school that was installed in early 2005. Note that the name of the school has been changed and the exact location of the school and name of the involved parties (a Local Authority and a design consultancy) withheld for reasons of confidentially.

3.0.1 High View Junior School: RWH System Assessment

A Local Authority (LA) has been given the responsibility of designing and constructing a new junior school in their region. The school has a term-time occupancy of 680 pupils and staff, consisting of 340 males and 340 females. In the interests of sustainability, the LA want to include a rainwater harvesting system within the project. However, before a decision is made as to whether or not to include one, they require an analysis to be undertaken to ensure that system performance will be acceptable in the long-term.

3.1 Tutorial 1: Goal and Scope Definition

A number of meetings were held with the LA in order to determine their reasons for wanting a RWH system, expectations, level of acceptable risk, availability of resources and assignment of responsibilities i.e. who pays/who maintains? The outcome of these meetings helped to determine the type of system required, acceptable uses for any harvested water and who is to be responsible for what.

Define Goals

The stated goals of the system were:

- To save money in the long-term.
- To help conserve water resources by reducing reliance on mains water.
- Compliance with sustainable development initiatives e.g. Local Agenda 21.
- Good PR – “green” credentials
- To provide an educational tool for pupils and staff.

<u>Outcomes</u>

The results of the Goal Definition phase were as follows:

- General agreement that a RWH system could be desirable, but LA would not make any judgement until the analysis results were available. Decision as to whether to implement or not was put on hold pending further information.

Define Expectations

Expectations of the system were stated as:

- Significant long-term savings as compared to using a mains-only system.
- Significant reduction in amount of mains water used.
- The design life of the school was estimated as 65 years, so this would be an acceptable timescale over which to judge RWH system performance.
- Components need to be easy for a sub-contractor to install.
- System should be reliable, easy to use and easy to maintain.

<u>Outcomes</u>

- LA could not make any further decisions based on the first two points (long-term savings and reduction in mains water used) until analysis results were available.
- Regarding the last two points, a decision was taken to consider a proprietary system from an established RWH system supplier, preferably one with a good track record and reputation. The selected system should be of a tried-and-tested design in order to minimise risks e.g. risk of system failure due to design flaws.

Level of Acceptable Risk

Risk was considered to be a vital issue, with the level of acceptable risk being very low:

- Risk of long-term financial loss must be low
- Health and safety risk (e.g. infection) must be very low (negligible)
- Long-term maintenance must not become a financial burden

<u>Outcomes</u>

- Analysis must show that the risk of long-term financial loss is either zero or low.
- Health and safety risks must be zero or very low (negligible). For this reason a system with a UV disinfection unit deemed preferable. End-uses for any harvested water limited to W.C. and urinal flushing in order to minimise risk of water-borne infection.
- Funding for long-term maintenance must be sustainable. No further funding from the LA would be forthcoming and so the school must be able to pay for maintenance of the system out of savings in metered water bills. The analysis must show that this is a realistic proposal.

Availability of Resources

The LA were willing to provide up to £20,000 for capital costs but would not provide any additional funding for maintenance. The school board agreed to take on the responsibility of any future maintenance costs provided that these could be covered by the savings in metered water bills. The school is unlikely to have the technical expertise to perform all the required maintenance activities (e.g. check pump functioning) and so would have to pay an outside contractor to perform at least some of the activities.

Assignment of Responsibilities

- LA to provide capital cost funding of up to £20,000.
- School to pay for future maintenance out of metered water bill savings.
- Outside contractor to be hired for any maintenance activities that the school cannot perform in-house.

Configure Global Settings and Enter Project Details

Having decided that a RWH system analysis is both required and justified, it is time to load up the application. Before beginning the analysis proper, it is necessary to configure the global (application-wide) settings and to enter some details about the project itself.

Global Settings

From the System Map, select the Global Settings module (click the button located in the upper right-hand corner of the screen labelled “Global Settings”).

For the purposes of the tutorial, the default settings for the *System Map Options* (all enabled), *Select RWH System Cost Items* (all included), *Select Currency* (£) and *Select 1st Jan Day* (Monday) will suffice. All that needs changing is the current value for the analysis runtime. The school building under investigation has an estimated design life of 65 years, so we will use this as the length of time for the analysis. In the Analysis Runtime (yrs) field, enter 65 and press the return key (all such data entries need to be confirmed by pressing the return key once the required value has been input).

Project Details

Next, enter the information shown in table 3.1 into the Project Details module (accessible from the System Map screen):

Table 3.1 – Tutorial project details

Category	Field	Information to Enter
-	Date	*Automatically completed*
-	Project Reference	HVJS-001
Company Details	Name & Address	SUD Solutions PO Box 104 Leeds West Yorkshire LS13 9AA
	Contact	Richard Smith
	Phone	(0113) 234 567
	Fax	(0113) 246 789
	Email	support@sudsolutions.com
Client Details*	Name & Address	Local Authority Education Dept. The High Street Leeds LS1 5AB
	Contact	Tony Johnson
	Phone	(0113) 283 746
	Fax	(0113) 232 435
	Email	tony.johnson@local_authority.gov
Project Details	Project Title	High View Junior School
	Project Stage	Feasibility
Project Description	-	High View Junior School is a design-and-build project with a Local Authority acting as the design agency. A rainwater harvesting system has been proposed for toilet and urinal flushing. The purpose of this report is to investigate the whole life costs of the proposed system as compared to relying solely on mains-only water and to investigate the likely long-term financial savings

*Note: client details are fictitious

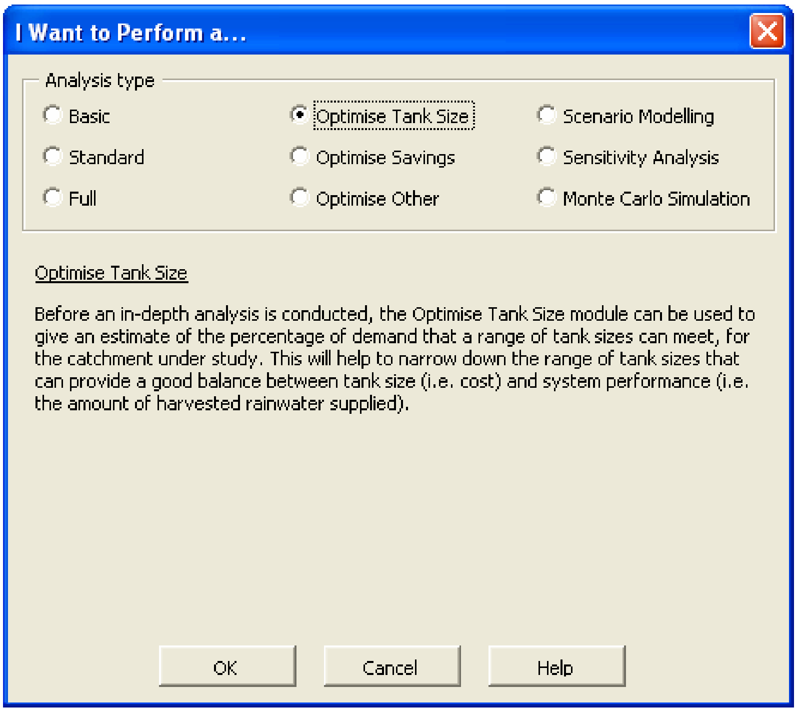
This concludes the first tutorial. The second will investigate the range of suitable tank sizes for the building under study.

3.2 Tutorial 2: Optimise Tank Size

Having agreed upon the goal and scope definitions and configured the application for use, the next step is to determine the range of suitable storage tank sizes.

At this stage it is prudent to make use of the “I Want to Perform a…” feature in order to simplify the appearance of the program’s interface. This will make it easier to follow the rest of the tutorial. Click the relevant box on the System Map screen (located on the right-hand side in the *Miscellaneous* section) to open the dialog box shown in figure 3.1.

Figure 3.1 – The “I Want to Perform a…” dialog box



This feature works by allowing the user to choose from a range of analysis types and then customising the application’s interface to suit the selected option. On the System Map screen, any modules that are not required as part of the selected analysis type will be greyed out (although they can still be clicked on) to indicate that they are not needed. Further, if the modules that *are* required contain any unnecessary sections then these areas will either be greyed out or hidden from view entirely.

The “I Want to Perform a…” feature can be very useful when learning to use RainCycle since it helps prevent information overload and focuses attention on where it is needed. For example, selecting the Optimise Tank Size option greys out all non-essential hydraulic modules (storage tank, pump and UV unit) and analysis modules (all except the Optimise Tank Size and Miscellaneous modules). For the required modules, it greys out or hides the unnecessary elements i.e. the above average/high and below average/low parameters.

There are 9 types of analysis to choose from. Activating an option button brings up a brief description of that option in the bottom half of the dialog box. The best way to understand how this feature works is to experiment with it i.e. work through the options one at a time and see what changes each of them makes to the user interface.

For now, select the Optimise Tank Size option and click the "OK" button. It is time to start gathering the data needed for this tutorial.

Obtain Average Rainfall Data

Daily rainfall statistics for the catchment area under study were not available and so predefined average monthly rainfall depths (mm/month) from the Rainfall Profiles module will be used instead. The figures shown in table 3.2 are the average monthly rainfall depths for the England E & NE region as found in the Monthly Average Rainfall Data Sets sub-module.

Table 3.2 – Average monthly rainfall depths for study catchment

Month	Rainfall Depth (mm/month)	Month	Rainfall Depth (mm/month)
January	61	July	58
February	59	August	81
March	54	September	92
April	68	October	109
May	57	November	91
June	67	December	88

Total yearly rainfall = 885 mm per annum

Assess Proposed Catchment Area

The catchment plan area was measured from design drawings of the school. The roof area available for rainwater collection was found to be 1,845m^2.

The roof material consists of pitched roof tiles and so an expected runoff coefficient of 0.85 will be used (refer to table 2.1).

Determine Expected Rainwater Filter Coefficient

A standard coarse debris filter is to be located before the main storage tank. These typically have a filter coefficient of 0.90 and so this is an acceptable value for the system under investigation.

Calculate Average Additional Inputs (if any)

The system is intended to collect and store rainwater only and so there are no additional inputs to take into account.

Calculate Average Daily Demand for One Year

It is anticipated that demand will only occur Monday-Friday during term times and that any collected rainwater will be used for toilet (W.C.) and urinal flushing. Any shortfall in supply will be compensated for by mains top-up water.

The following information about the school's toilet facilities was obtained from design plans:

Appliance	Number	Flush volume (litres)
W.C.'s	28	6.0
Urinal ranges	10	7.5

On the System Map screen, select the Water Demand module and from there select the Demand Calculator sub-module. This module has two demand calculators available. One for domestic systems and the other for school/commercial (or similar) systems. We want the School/Commercial calculator so click the corresponding navigation tab at the top of the screen. The word 'Viewing' will appear over the School/Commercial tab, indicating that this section of the module is currently active.

Tip: If any of the features in this module are unclear then refer to the comments which have been inserted in cells throughout the worksheet (denoted by a small red triangle in the top right-hand corner of a cell). To view a comment, hover the mouse pointer over the corresponding cell for a few seconds.

Enter the following information into the Demand Calculator module:

Heading	Item	Value
Occupancy Details	Number of males	340
	Number of females	340
W.C. (Toilet) Flushing	Volume per flush (litres)	6.0
	% of males who visit W.C. per day	30%
	Number of visits per day for above	1
	% of females who visit W.C. per day	100%
	Number of visits per day for above	3
Urinal Flushing	Volume per flush (litres)	7.5
	Number of urinal ranges	10
	Operating time (hrs/day)	8.0
	Number of hours between flushes	0.5

If the figures have been entered as shown then the combined total will be given as **7.932m^3/day**. This is the figure that we will use for the term-time period, Mondays to Fridays. It is assumed that no water demand occurs during weekends or school holidays.

Input Data Into RainCycle

We now have all the data required to run the Optimise Tank Size analysis. Table 3.3 shows a summary of the data collected so far.

Table 3.3 – Summary of data collected for Step 1

Parameter	Value
Average annual rainfall data	*See table 3.2*
Catchment surface area	$1,845m^2$
Catchment expected runoff coefficient	0.85
Expected rainwater filter coefficient	0.90
Average additional inputs	$0m^3$/day
Average daily water demand	$7.932m^3$/day*

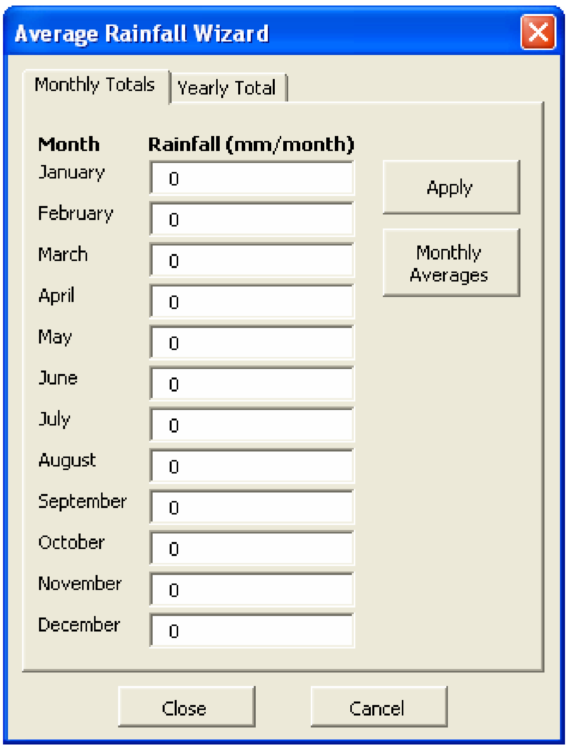
*During term-times, Monday-Friday only.

It is now time to input the above data into RainCycle.

Input Average Rainfall Data

On the System Map screen, select the Rainfall Profiles hydraulic module. We are going to use one of the rainfall data sets provided with RainCycle and for this it is necessary to select the Monthly Average Rainfall Data Sets sub-module. There are two ways in which to do this 1) click the button located in the top right-hand corner of the Rainfall Profiles screen labelled "Rainfall Data Sets" 2) open the Average Rainfall Wizard, select the tab labelled Monthly Totals and then click the button labelled "Monthly Averages" (see figure 3.2).

Figure 3.2 – Average Rainfall Wizard



Note that in the Rainfall Data Wizard it is also possible to input a single rainfall figure (in mm/yr) using the Yearly Total tab. In this case, when the Apply button is clicked the single figure will be disaggregated into daily averages for one whole year, with all days assumed to have the same amount of rainfall. This method is likely to be inaccurate however as it does not take into account seasonal variations in rainfall patterns. Alternatively, actual daily rainfall statistics can be copied/pasted directly into the relevant cells, assuming these figures are available.

Select the Monthly Averages sub-module using either of the two previously mentioned methods. This sub-module has several features which are explained in more detail below.

UK Regional Rainfall Map
Shows a map of the UK divided into 10 rainfall regions.

Select UK Region from List
RainCycle already contains monthly average rainfall data for each of the areas shown on the UK regional rainfall map. To select a data set, choose the required region from the drop-down list. The data for the chosen region will appear in the Currently Selected Rainfall Statistics tables. To edit the existing UK data sets, click the text that says Edit which is located next to the drop-down list.

Select User Defined from List
There are 20 user definable data sets that can selected from a drop down list. Each of these can be edited to suit specific requirements. Click the text that says Edit which is located next to the drop-down list to view the user definable data sets. Each data set has a number of editable fields:

- Rainfall Name: the name of a given rainfall profile e.g. its location
- Type: the type of rainfall e.g. regional, local
- Area: the name of the area that the rainfall data relates to
- Monthly Rainfall Depths: enter the actual rainfall data under the relevant month

Currently Selected Rainfall Statistics
This is where the currently selected rainfall data is displayed, along with the Type of rainfall data (regional or user-defined) and the Area that the rainfall data relates to. The button at the bottom labelled “Transfer Current Data” copies the monthly data currently in the table to the Rainfall Profiles module, average rainfall range. Monthly rainfall depths are disaggregated into equivalent daily rainfall depths and placed in the average rainfall column. If data is present in the table that has not been transferred, a message will appear underneath the table that states “current data has yet to be transferred” in order to remind the user that the data is not yet in use.

The area under study is located in Yorkshire which falls within the boundary of the England E & NE region. From the Select UK Region from List drop-down menu, select England E & NE. Rainfall data for this region will appear in the Currently Selected Rainfall Statistics tables.

Click the Transfer Current Data button to copy the figures to the Rainfall Profiles module, average rainfall range.

Once the data has been copied, a message box will appear stating “Transfer complete”. Close this and go back to the System Map screen (click the button in the top-right hand corner of the screen labelled System Map). Notice that the middle Status Box located underneath the Rainfall Profiles module box has turned green, indicating that data has been input into the average rainfall range.

Select the Catchment Surface module. Enter the catchment surface area and expected runoff coefficient values as shown in figure 3.3.

Figure 3.3 – Catchment surface parameters

Catchment Area		
Surface area	1,845	m^2

Runoff Coefficients		
High		Range 0-1
Expected	0.85	
Low		

First-Flush		
First-flush volume	0	litres

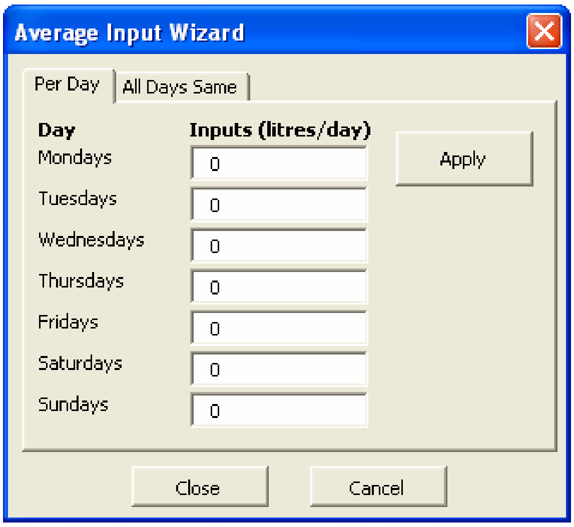
Next select the Rainwater Filter module from the System Map and enter the expected rainwater filter coefficient as shown in figure 3.4.

Figure 3.4 – Rainwater filter parameters

Filter Coefficients		
High		Range 0-1
Expected	0.90	
Low		

Now select the Additional Inputs module. This module allows for the inclusion of any water entering the tank in addition to rainwater, e.g. greywater. In this example there are no additional inputs but if there were then this module would be used to represent them, in litres per day. Data can be entered manually into the appropriate cell ranges or the input wizards can be used to enter information in a similar fashion to the rainfall wizards (see figure 3.5).

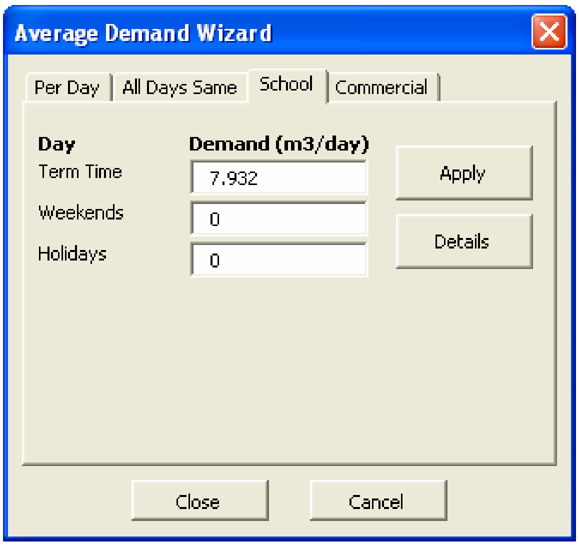
Figure 3.5 – Average Additional Inputs Wizard



Return to the System Map and select the Water Demand module. This is where the anticipated water demand profiles and volumes are input. Note that there is a sub-module called "Water Demand Wizards: Data Sets" which can be accessed by clicking the button labelled "Data Sets" (located in the top right-hand corner of the screen) or from the water demand wizards by clicking the button labelled "Details" (when shown). The function of this sub-module will be explained shortly, so don't click the button just yet – just be aware that it exists.

Each water demand wizard has a number of tabs that allow a variety of different demand patterns and associated water volumes to be quickly input into the module (see figure 3.6).

Figure 3.6 – Average Water Demand Wizard



The available options are as follows:

Per Day

Input water demand on a weekday basis (Monday-Sunday inclusive).

All Days Same

Allows only one entry which is applied to every day of the year.

School

Allows different water demand profiles to be input for Term-times, Holidays and Weekends. To view or edit the demand profiles, click the Details button to see the Water Demand Wizards Data Sets sub-module (click the button now). This allows the user to specify which days of the year should be classified as term times, holidays or weekends (although it can be assumed weekends will always mean Saturday and Sunday). The default settings correspond to typical term dates for UK schools. The contents of each cell can be changed to whatever is required by selecting a cell and choosing an entry from the drop-down list that appears. The cells are also colour-coded to show what type of day is being represented. Blue indicates a term-day, purple indicates weekends and grey represents holidays.

Commercial

Allows different demand profiles to be input for Workdays, Saturdays, Sundays and Holidays. The principle is the same as for the school demand profile and can be edited in a similar fashion. The default settings are for a typical UK business with working days being Monday-Friday inclusive, Saturdays and Sundays are self-explanatory and holiday periods are UK bank holiday dates. Again, the contents of the cells can be changed to represent a different demand profile and the cells are colour-coded to show what type of day is being represented. Blue for workdays, purple for Saturdays & Sundays and grey for holidays.

The commercial profile can be used to represent any number of building-types, such as offices, shopping centres, industrial buildings, universities, hospitals, public buildings and so on.

The default settings in the school profile are acceptable for the tutorial so go back to the Water Demand module by clicking the button in the top right-hand corner labelled “Back”.

Open the Average Water Demand Wizard, select the School tab and input the following:

Term-times: 7.932
Weekends: 0
Holidays: 0

The term-time demand was calculated earlier in this section. It is assumed that there will be no demand during weekends or holiday periods. Once the figures have been input, click the Apply button. The spreadsheet will then update using the school demand profile and associated water volumes, giving a total yearly demand volume of 1,546m^3/yr. Once the spreadsheet has finished inputting the figures, a message box will appear that states “Data successfully applied”. Click the OK button to close this box.

All the data that is required to run the tank size optimisation analysis has now been entered. On the System Map screen click the Optimise Tank Size box. This will take you to the storage tank optimisation screen. This module has a number of features:

Summary of Required Parameters

Displays a summary of the values entered thus far for the parameters that are to be used by the optimisation routine. If changes have been made since the last analysis was run then the corresponding cell in the Value column will turn yellow. Also, the simulation cannot be run if there are errors present. If all the data in the tutorial up to this point has been entered correctly then the figures in the table will match those shown below:

Rainfall Profiles: average rainfall profile	885 mm/yr
Catchment Surface: catchment area	1,845 m^2
Catchment Surface: expected runoff coefficient	0.85
First Flush Volume	0 litres
Rainwater Filter: expected filter coefficient	0.90
Additional Inputs - average annual input	0.00 m^3/yr
Water Demand: average annual demand	1,546 m^3/yr

Analysis Criteria

Max. tank size to simulate (m^3) specifies the maximum tank size that the computer should simulate before it stops the analysis. The maximum tank size that can be simulated is 1000m^3 whilst the lowest is 2m^3. The computer will *always* attempt to analyse the first two tank sizes (1m^3 and 2m^3) since it needs at least two data points to create the corresponding results graph.

Analysis Status

Reports the current condition of the analysis.

Simulating Tank Size (m^3)

Whilst the analysis is running this reports the size of the tank currently being modelled.

% Demand Met

The percentage of demand that can be met by the current tank size being simulated.

The following features are found in the Results section in the bottom half of the screen.

Table of Results

Stores all the results from the last analysis (tank size vs. % of demand met). Use the scroll bar on the right-hand side of the table to look through the results.

Tank Size vs. % of Demand Met Graph

Shows a graph of the percentage of water demand that each tank size simulated is predicted to meet (see figure 3.7). The graph shows all tank sizes from 1m^3 up to the last tank size that was simulated.

Figure 3.7 – Graph of tank size vs. % demand Met

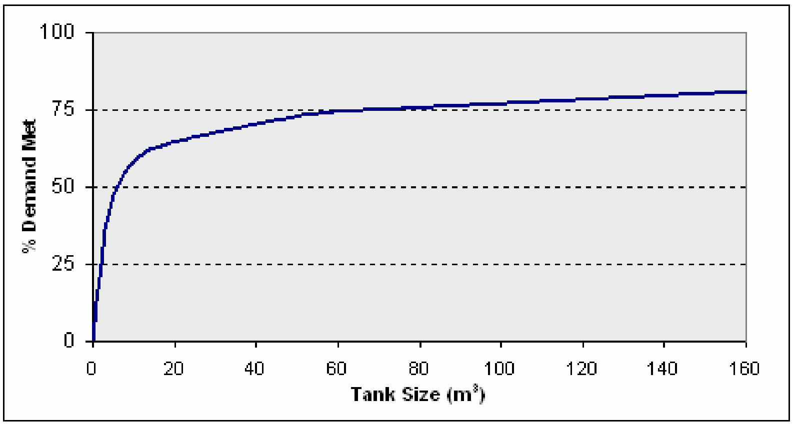


Figure 3.7 shows the graph that will be produced when the tutorial analysis is run. The graph shows a typical *tank size vs. percentage of demand met* profile and other studies concerning RWH system performance have found similar results. The percentage demand met rises quickly at first but then levels off somewhat and only small gains are seen for increasing tank sizes beyond this point. From a cost savings point of view, tank sizes far beyond the ‘knee’ of the graph should be avoided as they often produce only small increases in water savings but can increase capital costs significantly. Likewise, tank sizes corresponding to the steeply rising leg should be avoided *if possible* as the performance of these tanks is likely to be highly variable in practice. In the previous graph, a good range of sizes to consider would be between 15m^3 and 50m^3 as tanks within this range are likely to give a good compromise between the percentage of demand that can be met and capital costs.

Analyse the System

For the purposes of the tutorial, a maximum tank size of 200m^3 will be sufficient so enter 200 in the *Max. tank size to simulate* cell and press the green Analyse button. Simulations will run until one of three conditions are met:

1. The maximum tank size to simulate as specified by the user has been reached.
2. 100% of demand has been met.
3. Percentage of demand met has peaked i.e. it does not increase with increasing tank size.

The last two criteria were included as there is no need to simulate beyond these points since no additional water savings will be observed. In this case the simulation will run until it reaches a tank size of 160m^3, at which point the computer will detect that the % of demand met has peaked at 80.8% and will stop the simulation.

Once the analysis is complete, examine the graph (figure 3.7). It can be seen that the % of demand met rises steeply until a tank size of about 15m^3 is reached and then it gradually tails off until little improvement is seen for all tank sizes above about 50m^3. Therefore the tank sizes we are going to investigate further should fall within the 15-50m^3 range. Note that the range of tank sizes chosen for further study is to some extent an arbitrary decision. However, the results from the analysis will help to provide a clearer picture of the range of sizes that are likely to provide an acceptable level of performance.

Assess Predicted Performance

The Table of Results shows that a tank size of 15m^3 could meet 62.6% of the expected demand and a tank size of 50m^3 could meet 72.9% of demand. Whilst these figures represent a good performance for a RWH system such as this, it would still be worthwhile trying to improve the system. Two approaches are worth consideration:

1. Increase water demand – in this case not likely to result in any significant improvement since demand already exceeds supply.
2. Increase catchment surface area – will nearly always result in some improvement. However, in this case this was not possible since the entire roof area was already contributing to the RWH system and so could not be increased. The possibility of connecting other surface areas (e.g. pavements, car parking areas) was discussed but was considered to be too costly in this instance. However, these approaches may be feasible on other projects and so they are worth considering on a case-by-case basis.

This concludes the second tutorial. The following tutorial will examine the range of selected tank sizes (15-50m^3) in more detail and determine which tank size will give the best financial and hydraulic performance.

3.3 Tutorial 3: Optimise Savings

In tutorial 2 it was determined that the tank sizes deemed suitable for further investigation were in the range of 15-50m^3. The next step is to acquire capital and running costs for a number of tank sizes that fall within this range. It should be noted that, in reality, it is highly unlikely that any supplier will have a range of tanks that cover the whole 15-50m^3 range inclusively. Tanks are normally available in distinct sizes only e.g. 5, 10, 15, 27, 35m^3 and so on.

A rainwater harvesting company was contacted and asked to supply capital cost data for a number of tank sizes in the 15-50m^3 range. The Optimise Savings routine can simultaneously analyse up to 10 tank sizes at once and the company were able to supply cost data for 6 tanks within this range (one was 54m^3, slightly greater than the specified 50m^3 but close enough to be acceptable). This left some spare slots available and so costs for two smaller tank sizes were also obtained. Although tank sizes below 15m^3 are unlikely to perform as well as the larger tanks there is no harm in including them in the cost analysis. The information supplied by the company is shown in table 3.4.

Table 3.4 – Tank sizes and associated capital costs

Tank Size (m^3)	Capital Cost (£)
4.700	5,000
6.500	5,500
10.000	8,000
15.000	10,000
20.000	11,000
27.500	13,000
30.000	13,500
36.000	16,550
45.000	18,700
54.000	20,800

Note: all systems include a pump & UV unit

Note that this information is replicated in the Cost Examples sub-module

From the System Map screen, open the “I Want to Perform a…” dialog box and select the Optimise Savings option. Click OK and then open the Optimise Savings module and enter the figures shown in table 3.4 into the Tank Sizes to Analyse table. *Don’t press the Analyse button just yet*. We still need to obtain and input maintenance/operation costs and schedules, as well as some technical details about the system. (Refer back to chapter 2, figure 2.2 for further details).

Also note the button labelled Cost Examples, which is located in the top right-hand corner of the screen. Clicking this opens a sub-module with some generic cost examples for domestic and commercial/industrial systems. The prices include all capital (purchase and installation) costs and are ‘average’ values for the UK, year 2005. These can be used in the absence of more accurate data. However, wherever possible, site-specific costs should be obtained for all projects.

Determine Maintenance Requirements/Schedule and Associated Costs

The company that supplied the capital cost data also provide a maintenance service. For a flat fee of £250 a year they will send an engineer to site and perform the following activities:

- Check and clean all filters (leaf filter before the tank, pump filter in the tank and in-line filter located prior to the header tank).
- Check wiring and function of pump. Repair/replace pump if necessary, at no extra charge.
- Replace other components, if requested. Purchase of other components will have to be paid for independent of the maintenance contract e.g. UV lamp and filters. The engineer will fit these free of charge if they are made available.

Information on UV unit maintenance and associated costs was also obtained from the system supplier. They recommended that the UV lamp be replaced every 6 months (at a cost of £65) and that the UV filters also be replaced every 6 months (at a cost of £60).

A non-essential but recommended activity is catchment surface cleaning (i.e. clean the roof and clear gutters), which should be performed once or twice a year. Estimated costs for this are £100 per activity.

From the System Map screen, select the Whole Life Cost Details module. It is necessary to specify the planned maintenance schedule and associated costs by entering the relevant data in the Maintenance Activities and Associated Costs table.

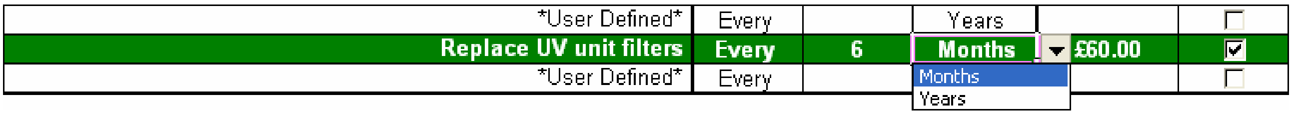
To enter these details in the maintenance table, either edit one of the cells in the Item column or use one of the predefined settings (note that the text of any Item can be changed to suit specific requirements). Enter the required maintenance frequency (in years or months) and then input the cost of the activity *at current prices*. Also don't forget to click the tick-box in the 'Select?' column so that RainCycle knows to take the required activities into account. The corresponding row will turn green to indicate that the item has been selected. The table should now look like figure 3.8.

Figure 3.8 – Planned maintenance schedule table

Maintenance Activities and Associated Costs					
Item	Frequency			Cost	Select?
Routine scheduled maintenance operations	Every	1	Years	£250.00	☑
Repair/replace pump	Every		Years		☐
Replace UV lamp	Every	6	Months	£65.00	☑
Clean filters/replace filter media	Every	6	Months	£60.00	☑
Annual cost of consumables	Every		Years		☐
Clean catchment surface	Every	1	Years	£100.00	☑
Water quality treatment items	Every		Years		☐
User Defined1	Every		Years		☐
User Defined2	Every		Years		☐
User Defined3	Every		Years		☐

In order to change the frequency setting from Years to Months so that the UV unit data can be input, select the corresponding cell that says “Years” and a drop-down list will appear. From the list, select Months (see figure 3.9).

Figure 3.9 – Set maintenance frequency timescale



Collect Remaining Whole Life Cost Data

Operating Costs

Discount Rate

Select an appropriate value for the expected discount rate (for more information on discount rates see appendix 1). Enter the value 3.5 in the Expected Discount Rate field.

If you do not want to take the discount rate into account on any future projects then simply enter zero in all three fields (high, expected and low). This will cause all future financial costs to be reported at their equivalent current prices i.e. what those items would cost if they had to be paid for right now.

Electricity Costs

Yorkshire Electricity were contacted in order to obtain the cost of electricity for the school. A price of 5.5p/kWhr was given. Enter the value 5.5 in the Expected Electricity Cost field.

Mains Water Costs

RainCycle comes with mains supply and sewerage costs for all primary UK Water Authorities (default prices will remain current until end March 2006). Note that under the current UK pricing system, there are two components to the cost of delivering mains water: the *supply* cost and the *sewerage* cost. In most cases these two costs are simply added together to give an overall cost for supplying water and then discharging it to the sewer system, on a per cubic metre basis.

From the WLC Details module, click the button labelled “Mains Cost Data Sets” which is located in the top right-hand corner of the screen. This brings up a sub-module called “Mains Supply & Sewerage Cost Data Sets”. This sub-module is essentially the user-interface for a database of mains cost information. The user selects options from a number of drop-down lists and the spreadsheet will retrieve the cost data associated with the selected items. There are several on-screen features, which are explained in more detail on the following page.

Primary UK Water Authorities – Boundary Map

Shows the operational boundaries for the 10 main Water Authorities in England and Wales.

Select Building Type from List

The cost database has areas for four different building types: Commercial, Office, School and Other. For the default cost data sets, the mains supply and sewerage costs for all four building types are the same but they can be edited independently if necessary e.g. when creating user-defined data sets, the costs for different building types may vary and this can be taken into account.

Select Mains Supplier from List

Select the mains water supplier from the drop-down list.

Select Sewerage Company from List

Similar to the Select Mains Supplier from List item but refers to the cost to dispose of used mains water to the sewer system. Select the sewerage company from the drop-down list.

"Edit" Button

Clicking this button opens the cost database. By default it contains mains supply and sewerage cost data for the primary UK Water Authorities as well as information for a further 22 water utilities. The majority of UK water utilities are covered by the default database. Entries in the Water Authority Name, Mains and Sewerage columns can be edited i.e. if costs need updating due to price changes.

Currently Selected Cost Data

Shows a summary of the current data:

- Mains supply cost per m^3
- Sewerage cost per m^3
- Total cost: supply + sewerage per m^3

Allow Manual Input

Clicking the associated checkbox allows the user to manually input the mains supplier, sewerage company, supply cost and sewerage cost.

For the tutorial, select "School" for the building type. Both the mains supplier and sewerage company are Yorkshire Water. Select this water authority from the drop-down lists and then click the "Transfer Current Data" button. This copies the *total* cost per cubic metre (£1.92) to the expected Mains Water Cost column in the WLC Details module. Once this has been done, click the button in the top right-hand corner of the screen labelled "Back".

It is also possible to simply enter the total expected Mains Water Cost directly into the relevant cell in the WLC Details module.

Water Disposal Cost

There is no disposal cost for water originating from the RWH system, so enter 0 in the expected Disposal Cost field.

Obtain or Estimate RWH System Technical Details

Technical details for the RWH system were obtained from the system supplier.

Pump Details

Enter the following details in the Pump module:

Power rating of pump (kW)	1.0
Pumping capacity (l/min)	60

UV Unit Details

Enter the following details in the UV Unit module:

Power rating (W)	55
Operating time (hrs/day)	24

All the data that is required for the Optimise Savings analysis has now been entered. From the System Map screen, select the Optimise Savings module. If the data has been entered correctly, then the Summary of Required Parameters table will contain the following information:

Rainfall Profiles: average rainfall profile	885 mm/yr
Catchment Surface: catchment area	1,845 m^2
Catchment Surface: expected runoff coefficient	0.85
First-Flush Volume	0 litres
Rainwater Filter: expected filter coefficient	0.90
Additional Inputs - average annual input	0.00 m^3/yr
Water Demand: average annual demand	1,546 m^3/yr
Power Rating of Pump	1.0 kW
Pumping Capacity	60 l/min
UV Unit Power Rating	55 W
Discount Rate: expected discount rate	3.5 %
Electricity Cost: expected electricity cost	5.5 p/kWhr
Mains Water Cost: expected water cost	1.92 £/m^3
Water Disposal Cost: expected cost	0.00 £/m^3
Number of Active Maintenance Items	4

To run the analysis, click the green Analyse button. Click the button now. The analysis will only take a few seconds to run and the results will be displayed in the Latest Simulation Results table. The results should match those presented in figure 3.10, which have been sorted according to Savings over 65yrs using the Results Sort Criteria table.

Figure 3.10 – Results from the optimise savings analysis

Use Top Rank	Latest Simulation Results (65 years)			
Tank Size (m^3)	Capital Cost	Savings over 65yrs	Pay-Back Period (yrs)	Demand Met (%)
30.000	£13,500	£22,700	12	67.8
20.000	£11,000	£22,685	10	64.6
27.500	£13,000	£22,584	11	67.0
15.000	£10,000	£22,176	9	62.6
36.000	£16,550	£20,857	15	69.3
10.000	£8,000	£20,666	8	58.1
45.000	£18,700	£20,518	16	71.7
54.000	£20,800	£19,867	18	73.5
6.500	£5,500	£17,805	7	51.2
4.700	£5,000	£14,407	8	46.2

Note: results have been sorted according to savings over 65yrs

Assess Results

From a long-term savings perspective, the results show that *all* the tank sizes simulated have the potential to save considerable sums of money. The best is the $30m^3$ tank, which indicates savings of £22,700 over 65 years of operation. Note that the smaller tank sizes of $4.7m^3$, $6.5m^3$ and $10m^3$, which are outside the range of tank sizes initially chosen, also show good results, particularly for the pay-back periods. At between 7 and 8 years, they have the shortest pay-back times of any of the tanks simulated. If a quick financial turn-around was the primary criteria, these could be a good choice of tank.

For the purposes of this tutorial, we are going to select the $30m^3$ tank. It shows the best potential long-term savings, the pay-back period of 12 years is not excessively long considering the type of building it is going to be installed in (the school has an expected service life of at least 65 years) and the percentage demand met value is a respectable 67.8%. Enter the chosen tank's details into the relevant modules by clicking the button located in the top-left hand corner of the results table labelled “Use Top Rank”. This transfers the details of the tank currently at the top of the results table into the relevant modules (tank size to the Storage Tank module and capital cost to the WLC Details module). Alternatively, input the details manually into the relevant modules.

This concludes the third tutorial. Tutorial number four will cover the collection of the remaining data necessary to conduct a more thorough analysis of the selected $30m^3$ tank.

3.4 Tutorial 4: Collect and Input Remaining Data

This tutorial focuses on gathering the remaining data needed for the scenario modelling, sensitivity analysis and Monte Carlo simulation aspects. The required data consists of:

- Above/below average rainfall profiles.
- High/low catchment surface runoff coefficients.
- High/low rainwater filter coefficients.
- Above/below average additional inputs.
- Above/below average yearly water demand profiles.
- High/low capital and decommissioning costs
- High/low operating costs

In tutorials 5, 6 and 7 this data will be used as part of the scenario modelling, sensitivity analysis and Monte Carlo assessments.

It is important to remember that the values entered in the above average/high and below average/low fields should be *realistic*. Ideally they should represent the worst and best *possible* scenarios. There is no point in using values that will not occur in reality e.g. having high/low catchment surface runoff coefficients of 100% and 0% respectively is not recommended as neither of these values is likely to occur in practice.

On the System Map screen, open the “I Want to Perform a…” dialog box and select the Full Analysis option in order to activate all modules and associated sections.

Obtain or Calculate Above and Below Average Rainfall Profiles

For the above average rainfall, we are going to add 25% to the average rainfall intensities to take into account the possible future effects of climate change in case this results in an overall increase in the amount of rainfall. In the Rainfall Profiles module, open the Above Average Rainfall Wizard and select the Monthly Totals tab. There is a button located on this tab labelled “Avg. plus” and a percentage figure in a box underneath, which can be altered to any number between 0 and 100 using the spinner arrows. Clicking this button copies across the current values from the average monthly totals (assuming these have been input) and increases these by the percentage shown. Make sure the figure is set to 25% and click the “Avg. plus” button. The monthly average rainfall figures previously selected for the region under study (England E & NE) will be copied across, plus 25%. The figures in the Above Average Rainfall Wizard should now match those shown in table 3.4. Click the Apply button to place the above average monthly rainfall data into the module.

Table 3.4 – Above average monthly rainfall depths

Month	Rainfall Depth (mm/month)	Month	Rainfall Depth (mm/month)
January	76.25	July	72.5
February	73.75	August	101.25
March	67.5	September	115
April	85	October	136.25
May	71.25	November	113.75
June	83.75	December	110

Total yearly rainfall = 1,106 mm per annum

Now open the Below Average Rainfall Wizard and repeat the previous instructions. Note that in this instance the average button says “Avg. minus”. This will *subtract* 25% from the average monthly rainfall figures and represents a reduction in rainfall i.e. if climate change results in reduced rainfall depths. The data in the Below Average Rainfall Wizard should now match that shown in table 3.5. As before, click the Apply button to place the data into the module.

Table 3.5 – Below average monthly rainfall depths

Month	Rainfall Depth (mm/month)	Month	Rainfall Depth (mm/month)
January	45.75	July	43.5
February	44.25	August	60.75
March	40.5	September	69
April	51	October	81.75
May	42.75	November	68.25
June	50.25	December	66

Total yearly rainfall = 663 mm per annum

Determine High/Low Catchment Runoff Coefficients

The roof of the building is classified as pitched roof tiles. Referring back to chapter 2, table 2.1 shows that a high coefficient value of 0.90 and a low value of 0.75 would be suitable. Input these details into the Catchment Surface module.

Determine High/Low Rainwater Filter Coefficients

The majority of modern primary rainwater filters have shown that, if maintained regularly, they consistently operate with a filter coefficient close to 0.90. For the purposes of the tutorial, enter a high filter coefficient of 0.92 (to represent peak performance) and a low coefficient of 0.85 (to represent a reduced performance if, for example, maintenance has not been carried out).

Calculate Above and Below Average Additional Inputs

No additional inputs are planned for the system, so ensure that both the above average and below average Additional Input ranges contain only zero values.

Calculate Above and Below Average Daily Water Demand for One Year

For the above and below average yearly water demand profiles, add/subtract 20% from the average term-time values respectively. Demand during weekends and holidays is still assumed to be zero. Use the Water Demand wizards to enter the following above/below average water demand figures. Select the School tabs and enter the following:

Above Average Demand		Below Average Demand	
Term Time:	9.518	Term Time:	6.346
Weekends:	0	Weekends:	0
Holidays:	0	Holidays:	0

Determine High/Low Values for Operating Costs

The following information needs to be entered in the WLC Details module.

Discount Rate

The UK Treasury is currently recommending a discount rate of 3.5%. The previous rate was 6.0% and so this is an acceptable figure for the high discount rate value. For the low discount rate, enter 0% (zero). This will allow us to see what happens if all future costs are assumed to be the same as current costs, rather than reducing them with a discount rate.

High discount rate (%)	6.0
Low discount rate (%)	0.0

Note that from the point of view of RWH system performance, a low discount rate is usually preferable. A high discount rate makes future financial expenditures seem less important and so, with a high rate, the on-going costs of a mains-only system will appear to become less and less over time. In comparison, RWH systems tend to require a relatively large initial expenditure of funds to install but cost relatively little to run. With a high discount rate, the emphasis is on short-term costs, not long-term savings and this may make RWH systems appear less financially attractive in the long-run than they actually are.

Electricity Costs

Future price increases in the cost of electricity of up to 25% have been predicted. Prices are unlikely to fall by the same amount that they are predicted to rise and a maximum reduction of 5-10% would be realistic. Enter the following values into the Electricity Cost cells:

High cost of electricity (p/kWhr)	6.9
Low cost of electricity (p/kWhr)	5.0

Mains Water Costs

Future price increases in the cost of mains water of up to 18% are predicted for some areas of the UK (mainly the south and south-east). Prices are unlikely to fall by the same amount that they are predicted to rise and a maximum reduction of 5-10% would be realistic. Enter the following values into the Mains Water Cost cells:

High cost of water (£/m^3)	2.27
Low cost of water (£/m^3)	1.82

Disposal Costs

There is no disposal cost, so ensure that all the Disposal Cost fields contain only zero values,

Determine High/Low Values Capital and Decommissioning Costs

A common approach to estimating high/low capital costs is to simply add/subtract an arbitrary percentage from the expected figure. +/-10% is commonly used in the construction industry and so this figure will suffice for our purposes. Enter the following figures into the Capital Costs cells:

High capital cost (£)	14,850
Low capital cost (£)	12,150

For the decommissioning costs, the expected value is zero since it is anticipated that removal of the system will be part of a larger contract to demolish the whole school and so removal of the RWH system will add a negligible amount to the overall decommissioning cost. However, for the high cost it can be assumed that there might be unforeseen difficulties with removing the system and so an arbitrary figure can be assigned to take into account the “worst-case scenario”. The low cost will still be zero since it cannot be less than this. Enter the following figures into the Decommissioning Costs cells:

High decommissioning cost (£)	2,000
Low decommissioning cost (£)	0

All the data that is required for a detailed analysis has now been entered. From the System Map, select the Data Entry Log module (located near the bottom right-hand corner of the screen). The figures in this module should match those shown in table 3.6

Table 3.6 – Data Entry Log: summary of parameter values

Module	Item	Value
Rainfall Profiles	Above average rainfall Average rainfall Below average rainfall	1,106 mm/yr 885 mm/yr 663 mm/yr
Catchment Surface	Surface area High runoff coefficient Expected runoff coefficient Low runoff coefficient	1,845 m^2 0.90 0.85 0.75
Rainwater filter	High filter coefficient Expected filter coefficient Low filter coefficient	0.92 0.90 0.85
Additional Inputs	Above average inputs Average inputs Below average inputs	0.00 m^3/yr 0.00 m^3/yr 0.00 m^3/yr
Storage Tank	Tank storage volume First-flush volume Mains top-up in tank? No. of drain-down intervals	30.000 m^3 0 litres No 0 /yr
Pump	Power rating Pumping capacity	1.0 kW 60 litres/min
UV Unit	Power rating Operating time	55 W 24 hrs/day
Water Demand	Above average demand Average demand Below average demand	1,856 m^3/yr 1,546 m^3/yr 1,237 m^3/yr
Whole Life Costs	High capital cost Expected capital cost Low capital cost	14,850.00 £ 13,500.00 £ 12,150.00 £
	High decom. cost Expected decom. cost Low decom. cost	2,000.00 £ 0.00 £ 0.00 £
	High discount rate Expected discount rate Low discount rate	6.0 % 3.5 % 0.0 %
	High electricity cost Expected electricity cost Low electricity cost	6.9 p/kWhr 5.5 p/kWhr 5.0 p/kWhr
	High mains water cost Expected mains water cost Low mains water cost	2.27 £/m^3 1.92 £/m^3 1.82 £/m^3
	High disposal cost Expected disposal cost Low disposal cost	0.00 £/m^3 0.00 £/m^3 0.00 £/m^3
	No. of maintenance activities	4 items
	Disconnection rebate	0.00 £/yr

Keeping Notes

It is advisable to keep up-to-date notes regarding the system being assessed. If you, or anyone else, has to return to the model in the future then having access to detailed notes will make it much easier to follow what has been done and what assumptions have been made.

Notes can be recorded in the Project Details module. Select the module and scroll down a few lines to see the "Project Notes" section. Example notes relating to the tutorial have already been input into this section. These do not form part of the automatically generated system reports and will not be printed. The notes are for user information only. This concludes tutorial four. The remaining tutorials concentrate on the detailed analysis and assessment of the RWH system under investigation.

3.5 Tutorial 5: Perform Scenario Modelling Analysis

Now that a full set of data has been entered into RainCycle it is time to begin a detailed analysis and investigation. In this tutorial we are going to perform a scenario modelling exercise in order to determine the best, expected and worst case scenarios for predicted system performance.

From the System Map, select the Analyse System module. This will take you to the Long-Term Analysis screen. This contains a lot of information and so a more detailed explanation of this module is warranted.

Summary of Active Parameters table

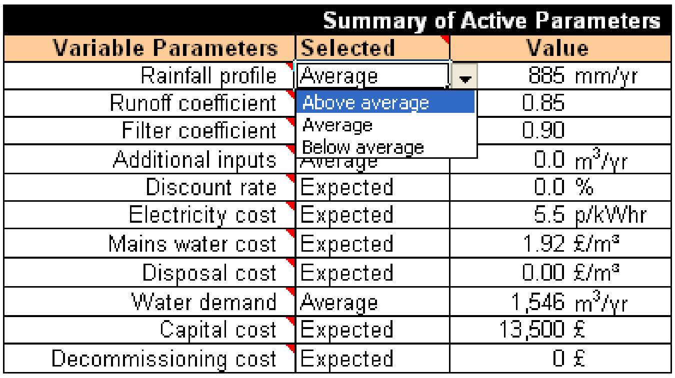
Displays the values of the currently selected (active) variable parameters as well as those of the fixed parameters, as shown in figure 3.11.

Figure 3.11 – Summary of Active Parameters table

Summary of Active Parameters		
Variable Parameters	**Selected**	**Value**
Rainfall profile	Average	885 mm/yr
Runoff coefficient	Expected	0.85
Filter coefficient	Expected	0.90
Additional inputs	Average	0.0 m^3/yr
Discount rate	Expected	0.0 %
Electricity cost	Expected	5.5 p/kWhr
Mains water cost	Expected	1.92 £/m^3
Disposal cost	Expected	0.00 £/m^3
Water demand	Average	1,546 m^3/yr
Capital cost	Expected	13,500 £
Decommissioning cost	Expected	0 £
Fixed Parameters	**Comments**	**Value**
Catchment surface area	No comment	1,845 m^2
First-flush volume	No first-flush	0 litres
Storage tank volume	No comment	30.000 m^3
Pump power rating	No comment	1.0 kW
Pump capacity	No comment	60 l/min
UV unit power rating	No comment	55 W
UV operating time	No comment	24 hrs

To change the currently selected value of a variable parameter, select the corresponding cell in the “Selected” column. A drop-down list will appear (see figure 3.12) that will allow you to select from a range of settings. Depending on the variable parameter, these will be either: above average/average/below average or high/expected/low. Once the required choice has been made, the rest of the module will update automatically using the new value.

Figure 3.12 – selecting the required variable parameter settings



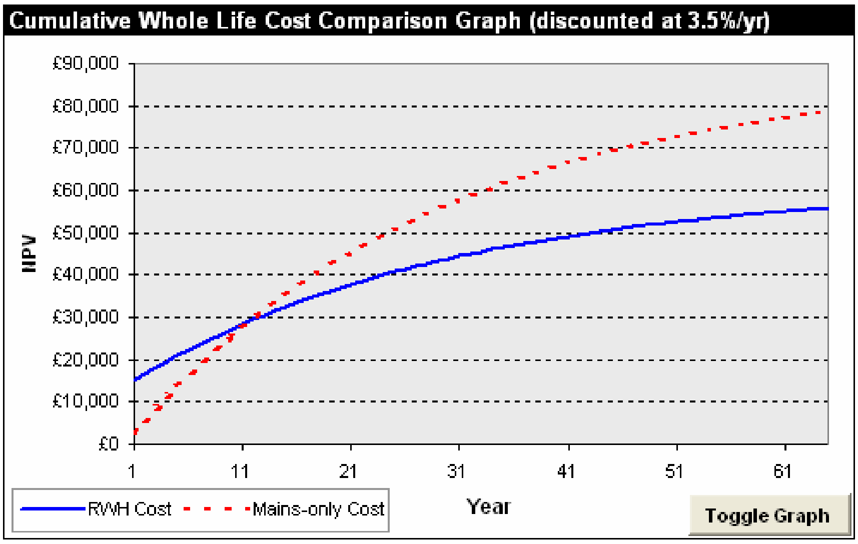
Summary of Active Parameters		
Variable Parameters	Selected	Value
Rainfall profile	Average	885 mm/yr
Runoff coefficient		0.85
Filter coefficient		0.90
Additional inputs	Average	0.0 m³/yr
Discount rate	Expected	0.0 %
Electricity cost	Expected	5.5 p/kWhr
Mains water cost	Expected	1.92 £/m³
Disposal cost	Expected	0.00 £/m³
Water demand	Average	1,546 m³/yr
Capital cost	Expected	13,500 £
Decommissioning cost	Expected	0 £

Later on in this tutorial we are going to model 3 possible scenarios using different combinations of the variable parameters.

Cost Comparison Graphs

There are two results graphs available for the long-term analysis and these can be viewed separately by clicking the button on the graphs labelled "Toggle Graph". The *Cumulative Whole Life Cost Comparison Graph* shows the latest results in terms of the cumulative WLCs of the modelled rainwater harvesting system and an equivalent mains-only system, for the selected analysis runtime (see figure 3.13). All future costs will be related back to their Net Present Value (NPV) using the selected discount rate.

Figure 3.13 – Cumulative WLC comparison graph



The *Year-by-Year Cost Comparison Graph* shows the annual expenditure for both the RWH system and an equivalent mains-only system, for each year over the selected analysis time period. Again, all future costs are related back to their Present Value using the selected discount rate.

Summary of Long-Term Analysis Results

This section is split into three parts: RWH system results summary, (equivalent) mains-only system results summary and comparative long-term financial summary.

The RWH System Results Summary consists of the following items:

Item	Explanation
RWH system WLC (NPV)	Rainwater harvesting system – whole life cost (at net present value)
Total water demand (m^3)	The total water *demand* from the system over the whole analysis period
Total water supplied (m^3)	The total water *supplied* by the system over the whole analysis period. Figure relates to harvested water only and does not include any mains top-up. Overall, demand met is 100% since any short-fall will be compensated for by mains supply
% demand met by harvested water	The percentage of demand that was met by the rainwater harvesting system over the whole analysis period (given by: water supplied/water demand x 100)

The Mains-Only System Results Summary consists of the following items:

Item	Explanation
Mains supply WLC (NPV)	Mains-only water supply – whole life cost (at net present value)
Total water demand (m^3)	The total water *demand* from the system over the whole analysis period
Total water supplied (m^3)	The total water *supplied* by the system over the whole analysis period
% demand met by mains water	The percentage of demand that was met by mains water. This will always be 100% for the mains-only system

The Comparative Long-Term Financial Summary consists of the following items:

Item	Explanation
RWH system savings	The whole life cost difference between the rainwater harvesting system and an equivalent mains-only system. If the rainwater system costs more in net present value terms then this region will turn red and display a negative number (effectively the net financial loss)
RWH system pay-back period (years)	The number of years it takes for the rainwater harvesting system to begin to save money i.e. the cumulative cost of supplying water from an equivalent mains-only system exceeds that of the rainwater harvesting system from this point onwards. If no savings are seen over the whole analysis period then this section will display “N/A”

Error Detection

If errors are detected in any of the modules, the message “*Warning! Errors detected. See Error Log*” will appear below the comparative long-term financial summary section and the relevant row of the Summary of Active Parameters table will turn red. It is probable that, even with errors present, the simulation will still give acceptable-looking results. In fact it may not even be apparent from the results that any erroneous data exists. However, any errors should still be tracked down via the Error Log module and corrected.

Average Per-Year Results

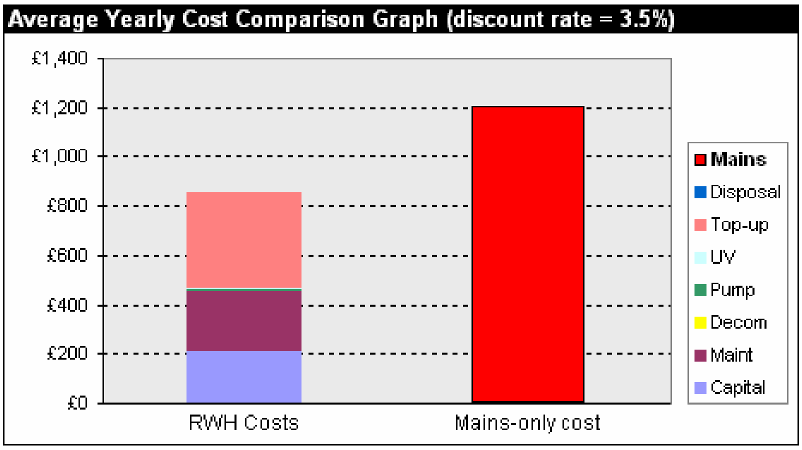
Average per-year financial and hydraulic results summaries are also available. To access this section, from the Long-Term Analysis screen, click the button located in the top right-hand corner labelled "Per-Year Results".

The financial element works by averaging the systems whole life costs over the selected analysis period and displaying the results on an equivalent per-year basis. It does this for *all* selected cost items, even those that are one-off costs (e.g. capital and decommissioning) or infrequent (e.g. long-term maintenance activities). It is possible to remove undesired cost items from the calculation by deselecting them in the Global Settings module.

The hydraulic element works by reporting the results for one year. In the hydraulic model, all years are assumed to be the same so there is no 'average' year as such.

The Summary of Average Per-Year Financial Results section highlights the yearly running cost of the RWH system and an equivalent mains-only system, as well as the annual cost savings (if any) provided by using rainwater in place of mains water. The average cost per cubic metre of water supplied from both systems is also shown, as well as various other performance-related data. A chart (see figure 3.14) shows the results graphically and breaks down the yearly RWH running cost into its component parts.

Figure 3.14 – Average Per-Year Results graph



The selected discount rate is applied to all future costs and this is reflected in the average yearly figures.

3.5.1 Overview of Scenario Modelling

RainCycle Advanced contains a scenario modelling feature which enables the user to examine how the RWH system will respond under a wide range of circumstances. We are going to analyse 3 scenarios in total, as summarised below:

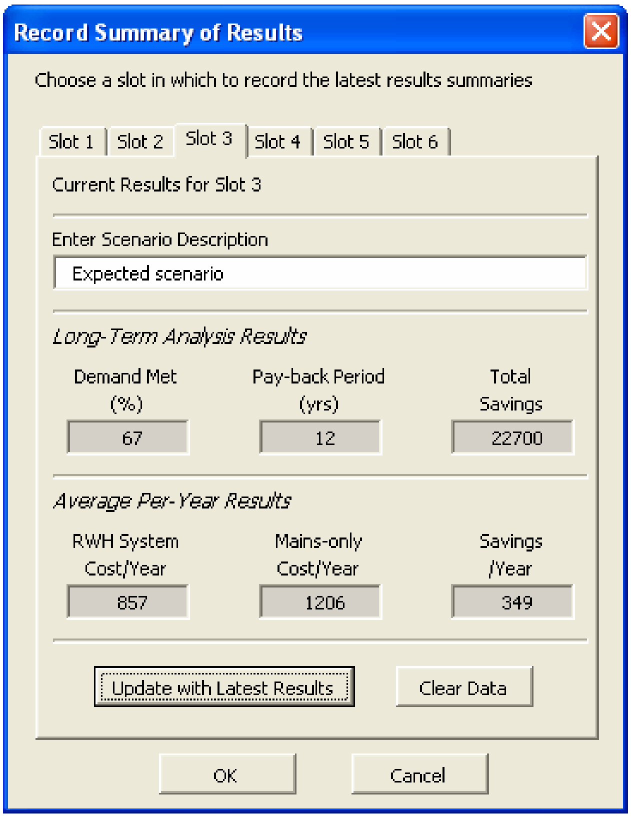
1. Best case scenario: all variable parameters set to values that will lead to the best performance for the RWH system.
2. Expected scenario: all variable parameter values set to average/expected.
3. Worst case scenario: all variable parameters set to values that will lead to a reduced performance for the RWH system.

We cannot know exactly what will happen in the future but by modelling a range of possibilities the performance of the system under a range of conditions can be evaluated. Providing that the data entered for the above average/high and below average/low values on the variable parameters is realistic, then the results from scenarios 1 and 3 can be considered as the performance 'boundaries' for the system under investigation. In practice, system performance is likely to fall between these two extremes. Scenario 2 can be considered as the most probable outcome but is by no means certain.

Recording the Scenario Modelling Results

RainCycle Advanced contains a feature that enables the results summaries of the current scenario to be recorded. On the Long-Term Analysis screen, there is a button located near the top right-hand corner of the screen labelled "Record Results". Clicking this opens a dialog box which contains 6 data 'slots' in which to record the results summaries (see figure 3.15).

Figure 3.15 – Record Summary of Results dialog box



Each data slot contains the following sections:

- Enter scenario description: a brief description of the scenario being recorded.
- Long-term analysis results: records the key information from the current long-term analysis, namely: percentage of demand met, RWH system pay-back period (years) and RWH system savings as compared to a mains-only system.
- Average per-year results: records the key information from the current average per-year analysis, namely: RWH system cost/year, equivalent mains-only system cost/year and RWH system savings/year as compared to a mains-only system.

To record the current results in the selected slot, click the “Update with Latest Results” button. Note that this will overwrite any existing data in that slot. To clear all data from the active slot, click the “Clear Data” button. Any recorded results are also replicated in the Full Report.

3.5.2 Perform Scenario Modelling Exercise

It is now time to run through the three different scenarios. For scenario one (best-case), select the following settings for the variable parameters. The analysis results will update automatically with each new selection.

Scenario 1 – best case scenario: variable parameter settings

Parameter	Select	Comments
Rainfall profile	Above average	Take into account likely effects of climate change (+25%)
Runoff coefficient	High	Assuming a clean and well-maintained roof area
Filter coefficient	High	Assuming a clean and well-maintained filter
Additional inputs	Average	There is no additional inputs so selection does not matter
Discount rate	Low	Future costs have greater importance with lower discount rate
Electricity costs	Low	Reduces pump and UV unit running costs
Mains water cost	High	Increases the cost of the equivalent mains-only system
Disposal cost	Expected	There is no disposal cost so selection does not matter
Water demand	Above average	Assumes greater than anticipated use of toilet facilities (+20%)
Capital cost	Low	Optimistic value based on past experience (-10%)
Decom. cost	Expected	Expected cost is zero. Cannot be less than this value

Once the above selections have been made, open the “Record Results” dialog box and update slot 1 with the latest results. Enter an appropriate description in the “Enter scenario description” textbox (something along the lines of “Best-case scenario” will suffice). Then click the OK button.

For scenario 2 (expected), use the following settings:

Scenario 2 – expected scenario: variable parameter settings

Parameter	Select	Comments
Rainfall profile	Average	Anticipated value
Runoff coefficient	Expected	Anticipated value
Filter coefficient	Expected	Anticipated value
Additional inputs	Average	There is no additional inputs so selection does not matter
Discount rate	Expected	Anticipated value
Electricity costs	Expected	Anticipated value
Mains water cost	Expected	Anticipated value
Disposal cost	Expected	There is no disposal cost so selection does not matter
Water demand	Average	Anticipated value
Capital cost	Expected	Anticipated value
Decom. cost	Expected	Cost subsumed into larger decom. contract. Negligible value

Open the “Record Results” dialog box again and update slot 2 with the latest results. Enter an appropriate description in the “Enter scenario description” textbox (e.g. “Expected scenario”). Then click the OK button.

For scenario 3 (worst-case), use the following settings:

Scenario 3 – worst-case scenario: variable parameter settings

Parameter	Select	Comments
Rainfall profile	Below Average	Assumes climate change effects produce *less* rainfall (-25%)
Runoff coefficient	Low	Roof type or condition worse than expected
Filter coefficient	Low	Assumes reduction in efficiency due to lack of maintenance
Additional inputs	Average	There is no additional inputs so selection does not matter
Discount rate	High	Decision makers want an emphasis on short-term costs
Electricity costs	High	Increases pump and UV unit running costs
Mains water cost	Low	Reduces the cost the of equivalent mains-only system
Disposal cost	Expected	There is no disposal cost so selection does not matter
Water demand	Below Average	Assumes less than anticipated use of toilet facilities (-20%)
Capital cost	High	Unforeseen installation difficulties increase cost (+10%)
Decom. cost	High	Unforeseen decom. difficulties increase cost

Open the “Record Results” dialog box once more and update slot 3 with the latest results. Enter an appropriate description in the “Enter scenario description” textbox (e.g. “Worst-case scenario”). Then click the OK button.

All 3 scenarios have now been modelled and the results recorded, so set the selected settings for all the variable parameters back to average/expected.

Up to 6 sets of results can be recorded, so it would have been possible to model further scenarios if this level of detail was required. There are literally hundreds of available combinations when selecting the variable parameters and so a wide range of possibilities can be investigated. The user is not restricted to only looking at the best, expected and worst-case scenarios. It would also have been possible to simulate variations in the required maintenance activities as part of the scenario modelling exercise e.g. for the worst-case scenario we could have assumed that the “clean catchment surface” item needed performing twice a year instead of just once, and then examined the effect this had on the results.

One important point to remember with scenario modelling is that if any of the RWH system’s parameter values are changed (e.g. water demand, catchment surface area), any previously recorded results will *not* update to take these changes into account. It will be necessary to re-run and re-record the results for any previous scenarios that have been analysed.

3.5.3 Assess Scenario Modelling Results

Long-Term Analysis Results

If you’ve followed the tutorial correctly so far then the long-term results from the 3 different simulations will be the same as those shown in the following table:

Scenario	Demand Met (%)	Pay-Back Period (yrs)	Cost Savings (£/65yrs)
Best-case	73	5	147,604
Expected	67	12	22,700
Worst-case	56	N/A	-4,056

The above results demonstrate that, in terms of cost savings, the modelled rainwater harvesting system can be considered to be reasonably robust. The possible long-term cost savings reveal a wide degree of variation with the worst-case scenario showing some loss but it is not excessive considering the timeframe of 65 years.

The pay-back period is good for the first two scenarios (5 and 12 years) but doesn’t occur at all for the worst-case scenario. The anticipated lifetime of the new school building is at least 65 years and so, based on the scenario modelling results, it is probable that the system will have paid for itself, and begun to show a profit, within this timeframe.

In all cases, the percentage of water demand met is good, ranging from 84% to 56%, showing that significant water savings are possible for all the modelled scenarios.

The worst-case scenario is unlikely to occur in practice but when dealing with an extremely pessimistic or risk-averse decision maker/organisation, it can be worthwhile investigating the absolute worst case situation. If it can be shown that even the most pessimistic outcome results in only a relatively small overall financial loss, and that in practice this situation is extremely unlikely to occur in any case, then this could help to give the key decision makers more confidence in the rainwater system when deciding whether or not to implement it.

Average Per-Year Results

The average per-year results should match those in the following table:

Scenario	RWH Average Cost (£/yr)	Mains-Only Cost (£/yr)	Cost Savings (£/yr)
Best-case	1,942	4,213	2,270
Expected	857	1,206	349
Worst-case	660	598	-63

Again, as with the long-term analysis results, the above table demonstrates that the modelled system is reasonably robust in terms of achieving cost savings. The best and expected cases show that yearly savings are possible. The worst case shows a loss but this is not excessive (£63/yr) and is unlikely to occur in practice in any case.

This concludes the tutorial. The next one explains the principles behind the sensitivity analysis module and provides instructions on how to perform one.

3.6 Tutorial 6: Perform Sensitivity Analysis

3.6.1 Overview of Sensitivity Analysis

The purpose of a sensitivity analysis is to assess how susceptible the overall performance of a system is to changes in one or more variables. For instance, for the system under study here, we could change the value on the ‘water demand’ parameter and then examine what effect this has on the whole life cost of the system. If we run the analysis with the above average water demand value selected, and then again with the below average water demand value selected, we can examine the change this causes in the whole life cost of the system. If the change is only small, the system can be said to be *insensitive* to changes in the value of the water demand parameter. However, if the change is large then the system can be said to be *sensitive* to changes in this parameter. In the former case, as long as the upper and lower values are accurate then there is probably little need to be concerned about what value this variable takes in practice since (as long as it stays within the expected bounds) it will not have any great impact on overall system performance. However, in the latter case further investigation may be warranted if changes in the selected variable can be shown to significantly affect the overall performance of the system. In extreme cases, even small changes can have very large impacts.

In the case of the water demand example, if varying this parameter causes significant changes in the whole life cost of the system (or in the percentage of water demand that can be met or the pay-back period) then it can be said that the system is sensitive to changes in the water demand parameter. In this case, the following actions would be advisable:

1. Ensure that the high, expected and low water demand values are as accurate as possible. This will reduce the likelihood of the actual whole life costs being outside the predicted bounds, a situation which could result in the real long-term costs of the system being significantly different than those predicted (although if they were significantly *less* than predicted then this would be seen as a positive development).
2. Try and find ways to increase the water demand from the system as this will have a positive net effect on the whole life costs (i.e. they will go down).

We have already carried out a type of sensitivity analysis where several values are changed at the same time when we ran the 3 scenarios in tutorial 5. This was a good way of assessing how the system would respond to changes in several parameters at the same time, but it gave us little information about how each parameter affected the outcome *individually*. For this we need to perform a different type of sensitivity analysis and RainCycle Advanced comes equipped with a routine that makes this very easy to perform. The following steps are automatically carried out:

1. All variable parameter values are set to average/expected.
2. Starting with the first parameter, the value is set to above average/high and the effect that this has is recorded.
3. Then the parameter value is set to below average/low and the effect that this has is recorded.
4. The value is set back to average/expected and the routine moves on to the next variable parameter, repeating steps 1-4 until all the variable parameters have been investigated and the results recorded.

Note that this procedure does not change the currently selected settings for the variable parameters in the Long-Term Analysis module, neither does it affect the current results for the long-term or average per-year simulations. Nor does it require the user to select any of the values themselves since the sensitivity analysis is carried out entirely by the computer. It does, however, use the figures previously entered into the individual modules for the fixed and variable parameters.

Open the “I Want to Perform a…” dialog box and select the sensitivity analysis option. Click OK and then select the Sensitivity Analysis module from the System Map screen. To run the analysis using the latest parameter data, click the green Analyse button. Click the button now.

3.6.2 Overview of the Sensitivity Analysis Module

The sensitivity analysis module has five main components: Summary Table, Table Sort Criteria, the Analyse button, a results graph and a table which shows the status of the RWH system when all variable parameters are set to their average/expected values.

<u>Summary Table</u>

Shows a list of the sensitivity analysis results, sorted with respect to the variable parameters. The list is ordered so that the parameter that has the greatest overall effect on the system is located at the top and the parameter that has the least overall effect is located at the bottom. There are three columns in the table which show the changes that occurred. These are:

- Above Av / High – shows the change that occurred when a particular parameter was altered from average/expected to above average/high
- Below Av / Low – shows the change that occurred when a particular parameter was altered from average/expected to below average/low
- Total change – the absolute difference between the two above items.

Note that the figures in these columns will either be displayed as percentage values or as numeric values, depending on which option is selected in the Table Sort Criteria.

The column labelled “Graph ID” indicates where the parameters can be found on the corresponding histogram (numbers relate to the y-axis values).

<u>Table Sort Criteria</u>

There are two drop-down lists associated with this section. The “Sort table by” drop-down list allows the user to select from three options:

1. Savings over ‘x’ yrs: sorts the results in descending order according to the parameters that have the greatest effect on the total RWH system savings over ‘x’ years, where ‘x’ is the selected analysis runtime.
2. Pay-back period: sorts the results in descending order according to the parameters that have the greatest effect on the pay-back period, in years. Note that if the pay-back period exceeds the analysis runtime then the corresponding cells will display “N/A”. This is not an error in the sensitivity analysis routine. Rather, it simply indicates that the pay-back period is greater than the analysis runtime and so the pay-back period is unknown. It may also mean that the system does not show a profit at any point in the future i.e. if the yearly running cost of the RWH system continues to be more expensive than simply obtaining water from the mains.
3. Percentage demand met: sorts the results in descending order according to the parameters that have the greatest effect on the percentage of demand that the rainwater harvesting system can meet.

The “Value type” drop-down list allows the user to specify whether the results in the summary table should be displayed as percentage changes or as value (numeric) changes for the currently selected criteria (savings over ‘x’ yrs, pay-back period or % of demand met). The results graph will also change to represent the selected option.

<u>Analyse Button</u>

Pressing the green ‘Analyse’ button tells the computer to run the sensitivity analysis using the current data. Unlike the long-term analysis, the sensitivity analysis will not automatically update if the parameter values are changed and so the user has to initiate the procedure by clicking the analyse button. The results table and corresponding graph will automatically update once the latest analysis is complete.

<u>Results Histogram</u>

In the bottom left-hand section of the screen is a histogram which display the analysis results in graphical form. The blue bars show the change that occurs when a parameter is changed from average/expected to above average/high, and the red bars to the change that occurs when a parameter is changed from average/expected to below average/low.

The graph is also linked to the “Value type” field. It displays the results as either percentage changes or value (numeric) changes, depending on the current selection.

<u>Values When All Parameters are Average/Expected</u>

This table shows the values for: savings over ‘x’ yrs, pay-back period and the % of demand met for when all the variable parameters are set to their average/expected values. The values in this table are the benchmark by which sensitivity to changes in each of the variable parameters is measured. For instance, if the pay-back period when all variable parameters are average/expected is 8 years, then in the Summary Table a change of +4 years would mean that the pay-back period is equal to 12 years, or a change of +50%.

3.6.3 Assess Sensitivity Analysis Results

If you have not already done so, select the Sensitivity Analysis module from the System Map. Ensure that the Table Sort Criteria drop-down lists are set to “Savings over 65yrs” and “Show % changes” respectively and click the green Analyse button. The analysis will only take a few seconds to run and the Summary Table and results graph will update automatically. If all has gone well then the results will be the same as those shown in figures 3.16 and 3.17

Figure 3.16 – Summary Table showing sensitivity analysis results for RWH savings

Sorted Parameter List	Graph ID	Above Av/High	Below Av/Low	Total Change
Discount rate	5	-55.2%	233.0%	288.2%
Rainfall profile	1	46.2%	-51.4%	97.7%
Mains water cost	7	42.7%	-12.2%	54.9%
Catchment runoff coefficient	2	11.8%	-24.2%	36.0%
Rainwater filter coefficient	3	4.5%	-11.4%	15.9%
Capital cost	10	-5.9%	5.9%	11.9%
Water demand	9	0.0%	-4.2%	4.2%
Electricity cost	6	-1.3%	0.4%	1.7%
Decommissioning cost	11	-1.0%	0.0%	1.0%
Additional inputs	4	0.0%	0.0%	0.0%
Disposal cost	8	0.0%	0.0%	0.0%

Figure 3.16 shows the sensitivity analysis results in tabular form with regards to the percentage changes in rainwater harvesting system savings over 65 years. The results are automatically sorted, with the parameter that led to the greatest change at the top and the parameter that led to the smallest change at the bottom. The numbers in the Graph ID column relate to the numbers on the y-axis of the corresponding results histogram.

Figure 3.17 – Histogram showing sensitivity analysis results for RWH savings

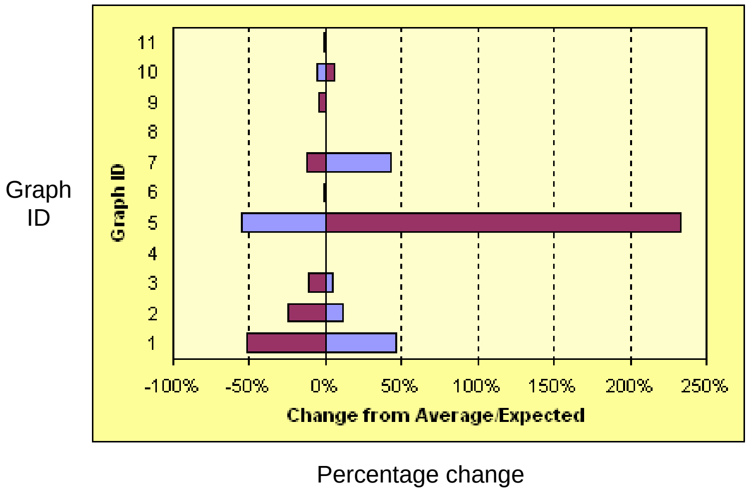


Figure 3.17 is a graphical representation of the tabulated results from figure 3.16. The information is the same, only in this instance it is displayed as a histogram. Similar results for the pay-back period and the % of demand met can be viewed by selecting the relevant entries in the Table Sort Criteria drop-down lists.

Interpreting the Results

So what do these results tell us? Looking at the histogram it is easy to see that, as far as the RWH system savings are concerned, variations in the discount rate, rainfall profile, mains water cost, catchment runoff coefficient and rainwater filter coefficient produce the most significant changes and so we will concentrate on these parameters.

The results are most sensitive to changes in the discount rate, which produced an overall % change in the RWH system savings of 288.2%, or £65,426! With such a large impact, it would be worthwhile ensuring that confidence in the selected discount rates is as high as possible. (See appendix 1 for further information on the discount rate).

The rainfall profile shows the second highest sensitivity. Although no-one can directly control the weather, it may be possible to influence local conditions that affect the amount of rainfall reaching the catchment surface. For example, overhanging trees can sometimes act as a barrier and prevent a portion of the rainfall from landing on the roof, or nearby buildings can have much the same effect if they are taller than the building under investigation, creating a 'rain-shadow'. In this instance it would be worthwhile to check the surrounding conditions to see if there are any physical obstructions that could affect the level of rainfall and to try and minimise the effects as much as possible e.g. if there are overhanging trees nearby then could the foliage be managed in such a way as to minimise the amount of rainfall they might intercept?

Mains water cost is next. There is not much that can be done about the supply and sewerage costs other than to ensure that the figures used in the analysis are as accurate as possible.

The catchment runoff coefficient shows the fourth highest sensitivity, with a total change of 36.0% (£8,168) in RWH system savings over 65 years. There is an entry in the maintenance activities for "clean catchment surface" which will help to keep the runoff coefficient from falling below the expected value. It is possible to see how much money it costs to perform this maintenance activity over the lifetime of the system. Return to the System Map and select the Analyse System module. From there, select the Detailed Results sub-module: Financial Results, and then click the Maintenance Costs tab. This will show an itemised breakdown of all the RWH system maintenance costs over 65 years. The "clean catchment surface" activity is performed once per year at a cost of £100 (at current prices), but because we are applying an expected discount rate of 3.5% then the *total* cost over 65 years comes to £2,641 and not £6,500 as one might expect. Given that changes in the catchment runoff coefficient can lead to variations in the RWH system savings of up to £8,000 over 65 years, then money spent on keeping the catchment surface clean can be considered to be a good investment.

Finally, changes in the rainwater filter coefficient may lead to a change in the RWH system savings of up to 15.9% (£3,613) over 65 years. The rainwater filter will be regularly cleaned as part of the yearly maintenance contract that the school has with the RWH system supplier and so, providing that this is carried out as planned, the rainwater filter should remain at or close to its peak operating efficiency.

It is also worth mentioning the water demand results. Only a small change is indicated: 4.2% (£958) over 65 years. This indicates that the limiting factor in the water demand/supply balance is the supply of water and not the level of demand. Increasing or decreasing the demand would make little difference to the amount of money saved and efforts would be better spent on trying to make more water available rather than trying to increase the usage what is already there.

Sensitivity Analysis Results – when do they matter?

There is no official 'threshold' above which one should be concerned about the sensitivity analysis results. Whether or not they are a cause for concern is an arbitrary decision and requires some degree of human judgement. However, performing a sensitivity analysis gives a good indication as to which variable parameter(s) can lead to the greatest variations in system performance and so appropriate measures can be taken to minimise any negative aspects and to maximise the positive.

This completes the sensitivity analysis tutorial.

3.7 Tutorial 7: Perform Monte Carlo Simulation

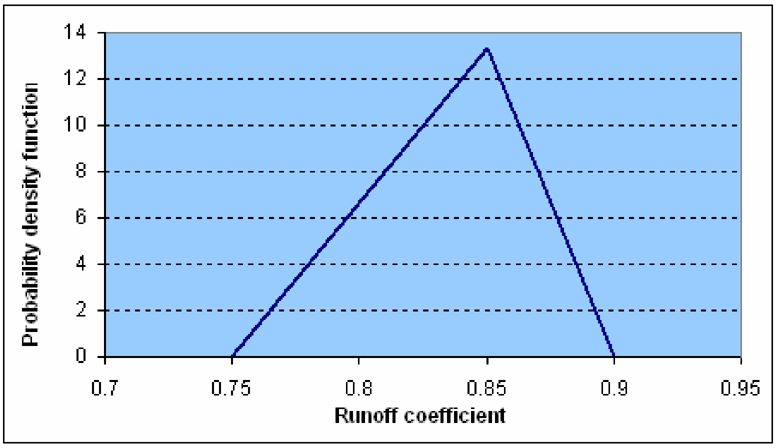
3.7.1 Overview of Monte Carlo simulation

Monte Carlo simulation is a well-established technique that involves the use of random numbers and probability distributions in order to solve problems. In the science and engineering fields, Monte Carlo simulation is often used for uncertainty analysis, system optimisation and reliability-based design. In the case of RainCycle Advanced, it is used to randomly generate new values for the variable parameters and then to run a system analysis using those new values. Results are presented as probability distribution graphs and histograms. It is possible to run thousands of simulations (iterations) and to assess RWH system response under a wide range of conditions.

Three values are required: highest most probable value (i.e. above average/high), most probable value (i.e. average/expected) and lowest most probable value (i.e. below average/expected). RainCycle derives these values from data input into other modules so there is no need to enter them in the actual Monte Carlo module

From these three values, and for every iteration, the program generates a new set of variable parameter values by randomly sampling from a set of *continuous* probability distributions (in this case triangular distributions). As an example, suppose we have 3 catchment surface runoff coefficients: high = 0.90, expected = 0.85 and low = 0.75. The most probable value is 0.85 and so the generated number is most likely to be close to this value (it will not equal 0.85 exactly) with a diminishing, but never zero, probability that the value will be closer to 0.75 or 0.90. If enough iterations are run (say at least several hundred) and the results plotted then the frequency of values chosen will resemble a triangle. That is, most of the values generated will be clustered around the most probable value of 0.85 with the number of values either side diminishing the closer they get to 0.75 or 0.90 (see figure 3.18).

Figure 3.18 – Triangular probability density function graph



If hundreds or thousands of such simulations are run then it is possible to use the results to predict the probability of the modelled RWH system meeting a given set of conditions e.g. the probability that long-term savings are equal to or greater than a given amount or that system pay-back occurs within a given timescale.

<u>Key Points</u>

- Monte Carlo simulation turns an otherwise deterministic model into a stochastic one.
- It is a good way of investigating system variability and assessing associated risk/likely performance.
- More realistic that a purely deterministic model since it allows system performance under a wide range of circumstances to be investigated.
- It offers a way to run thousands of tests on a system that would be impractical using other means.

There is one exception to the way that new parameter values are generated. The new values are created using continuous probability distributions except for the maintenance frequencies which utilise *discrete* probability distributions. The Monte Carlo simulation module has a sub-module called "Maintenance Probability Settings" which is accessible from the main module by clicking the button located in the top right-hand corner labelled "Maint. Probability". The user is required to input details about the high and low maintenance frequencies and costs for the active maintenance items. Costs are generated using the continuous probability distribution method and so there is a wide array of costs values that can be produced between the high and low values. However, for the maintenance *frequencies* this approach was not feasible and so the user has to enter the high/low frequency values and also the probability associated with each. In this case no new values are generated and the computer can only select from one of the existing three values (high, expected or low). The selection is made based on the probability of occurrence assigned to each possible frequency setting. Do not be concerned with this feature at the moment as we will come back to it later on in the tutorial.

3.7.2 Overview of the Monte Carlo Simulation Module

The Monte Carlo simulation module has five main components: simulation status, long-term savings, pay-back period, percentage of demand met and average yearly savings. Each of these can be selected via the navigation tabs located near the top of the screen.

The long-term savings, pay-back period, percentage of demand met and average yearly savings sections all have similar layouts and present the simulation results as a series of tables and graphs. For each section, three graphs are available: cumulative probability graph, a histogram and a frequency polygon chart. Each graph has its own help feature. Clicking the information icon labelled “Help” (located in the bottom right-hand corner of the screen) will open a dialog box that provides further information on the currently selected graph.

There is also a feature that allows the user to determine the probability of a specific event occurring e.g. the probability of achieving positive long-term savings or the probability that pay-back will be achieved within a given timeframe.

Simulation Status

Shows the current parameter values and maintenance frequencies/costs being simulated. User inputs are only required in the “Monte Carlo Simulation Criteria” table. Enter the number of iterations required, between 2 and 10,000. There is no ‘correct’ value for the number of iterations, although generally speaking no fewer than 200-300 should be run as any less is unlikely to produce a useful spread of results. Running 10,000 is more accurate but can take some time, depending on CPU speed. We have found that running 1,000 iterations gives a good compromise between speed and accuracy. There is no appreciable difference in the results obtained between running 1,000 and 10,000 iterations and the former takes considerably less time to perform.

There is also the option to turn screen updating on or off during the simulation. If OFF is selected then when the simulation is running the screen will only update every 50 iterations as opposed to every iteration if screen updating is ON. This does not affect the results in any way but may speed up the process to some extent.

This section also contains the Analyse button which, when pressed, causes the Monte Carlo to run (don’t press this just yet).

Long-Term Savings

Long-Term Savings Results table

Shows: maximum, mean (average) and minimum long-term savings achieved in the last simulation, the standard deviation (average distance from the mean) and the probability of achieving positive savings during the analysis runtime i.e. the percentage of results that showed long-term savings greater than or equal to zero.

Prob. of Savings >= ‘x’

Allows the user to enter a figure and the computer will determine the probability of achieving long-term savings *greater than or equal* to that figure. The entry must be greater than the minimum long-term savings and less than the maximum long-term savings as shown the results table.

Graph Options

Graphs available are:

- Cumulative probability graph: shows the probability of achieving savings greater than or equal to a given value.
- Histogram: shows the relative frequency of the long-term savings achieved in the last simulation.
- Frequency polygon: displays the same data as the long-term savings histogram but presents the information in a different way.

<u>Pay-back Period</u>

Pay-Back Period Results table

Shows: shortest, mean (average) and longest pay-back periods, standard deviation and probability of achieving pay-back within the given analysis runtime i.e. the percentage of results for which pay-back was achieved.

Prob. of Pay-Back Within 'x' Years

Allows the user to enter a value between 1 and 100 (years) and the program will determine the probability of achieving a pay-back period less than or equal to the input value.

Graph Options

Graphs available are:

- Cumulative probability graph: shows the probability of achieving pay-back with increasing time (years).
- Histogram: shows the relative frequency of the pay-back periods achieved in the last simulation.
- Frequency polygon: displays the same data as the pay-back period histogram but presents the information in a different way.

<u>% Demand Met</u>

% Demand Met Results table

Shows: maximum, mean (average) and minimum percentage of demand met by harvested water, standard deviation and probability of meeting 100% of demand using harvested water.

Prob. of % Demand Met >= 'x'

Allows the user to enter a value between 1 and 100 (%) and the program will determine the probability of achieving a percentage of demand met greater than or equal to the input value.

Graph Options

Graphs available are:

- Cumulative probability graph: shows the probability of meeting a minimum % of the total water demand using harvested water.
- Histogram: shows the relative frequency of the range of percentage demands met in the last simulation.
- Frequency polygon: displays the same data as the percentage of demand met histogram but presents the information in a different way.

<u>Average Yearly Savings</u>

Average Yearly Savings Results table

Shows: maximum, mean (average) and minimum average yearly savings achieved in the last simulation, standard deviation (the average distance from the mean) and probability of achieving positive average yearly savings i.e. the percentage of results that showed yearly savings greater than or equal to zero.

Prob. of Yearly Savings >= 'x'

Allows the user to enter a figure and the computer will determine the probability of achieving average yearly savings *greater than or equal* to that figure. The entry must be greater than the minimum average yearly savings and less than the maximum average yearly savings as shown the results table.

Graph Options

Graphs available are:

- Cumulative probability graph: shows the probability of achieving savings greater than or equal to a given value.
- Histogram: Shows the relative frequency of the savings achieved in the last simulation.
- Frequency polygon: displays the same data as the savings histogram but presents the information in a different way.

3.7.3 Setting High/Low Maintenance Activities and Costs

Before any Monte Carlo simulation can be conducted, it is necessary to enter information relating to the high/low values for the active maintenance items. This is done in the Maintenance Probability Settings sub-module. Access this module now by clicking the button located in the top right-hand corner of the Monte Carlo Simulation module labelled "Maint. Probability".

Maintenance Activities and Probability of Occurrence table

This is the data entry table and is similar in appearance to the Maintenance Activities and Associated Costs table found in the WLC Details module. Figure 3.19 shows the top section of the table.

Figure 3.19 – Section of the Monte Carlo Maintenance Activities table

Maintenance Activities & Probability of Occurrence						
Item	Selected?	Frequencies			Probability	Costs
Routine scheduled maintenance operations	Yes	Every	2	Years	0.25	£275.00
		Every	1	Years	0.50	£250.00
		Every	8	Months	0.25	£225.00
Repair/replace pump	No	Every	1	Years	0.33	£0.00
		Every	0	Years	0.34	£0.00
		Every	1	Years	0.33	£0.00

Important points to note about the maintenance activities table are:

- Only items that have been selected (made active) in the WLC Details module are used as part of the Monte Carlo simulation. Selected items are highlighted in the table by changing the background colour of the frequencies, probability and cost rows to white. Deselected (inactive) items have a grey background colour.
- For all active items, the middle (expected) set of values remains grey because these are linked to the values in the WLC Details module and cannot be changed here. If you want to change them then this must be done in WLC Details module itself.
- For high/low frequencies: set the frequency the same way as you would for the maintenance items in the WLC Details module i.e. enter a frequency between 1 month and up to a maximum of the analysis runtime. Assign a probability between 0 and 1 to each to represent the perceived chance of each event occurring e.g. if there is a 25% chance of the high maintenance frequency occurring then enter 0.25 in the corresponding probability cell.
- The sum of all three probabilities must always equal 1. If this is not the case then an error message will be produced and the computer will not allow the Monte Carlo simulation to be run until the error is corrected. Note that the expected probability is automatically calculated and so the user only has to input the high/low probabilities.
- For maintenance costs, enter high/low costs only. No probabilities need assigning.

In this tutorial, there are 4 active maintenance items: routine scheduled maintenance operations, replace UV lamp, clean filters/replace filter media and clean catchment surface. The assignment of high/low frequencies is to some extent arbitrary and can be based on available data, past experience and/or component supplier's advice. In this instance probabilities of 0.25 (25%) will be assigned to all high/low frequencies. The computer will automatically calculate the probability of occurrence for the expected scenario which will be

0.5 (50%). For the high/low costs, the standard practice of adding/subtracting 10% from the expected cost has been followed. For each item, enter the relevant details shown in table 3.7.

Table 3.7 – Monte Carlo simulation maintenance details

Item	Frequencies	Probability	Cost (£)	
Routine scheduled	Every 2 years	0.25	275.00	High
maintenance operations	Every 8 months	0.25	225.00	Low
Replace UV lamp	Every 1 years	0.25	71.50	High
	Every 4 months	0.25	58.50	Low
Clean filters/replace filter	Every 1 years	0.25	66.00	High
media	Every 4 months	0.25	54.00	Low
Clean catchment surface	Every 2 years	0.25	110.00	High
	Every 6 months	0.25	90.00	Low

Once the above details have been input, return to the main Monte Carlo simulation module (click the Back button). In the Simulation Status section, enter 1,000 into the Iterations field and click the green Analyse button to start the simulation. The analysis may take a while to complete – 10-20 minutes is not uncommon on a modern machine, so this would be a good point to take a short break until the simulation is finished.

3.7.4 Assess Monte Carlo Simulation Results

Once the simulation is complete, select the Long-Term Savings section by clicking the relevant navigation tab. We will go through the Long-Term Savings results in details but only provide a summary for the Pay-Back Period, Percentage of Demand Met and Average Yearly Results since the same principles apply to all the results.

Long-Term Savings Results table

The Long-Term Savings Results table should contain values similar to those shown in table 3.8 (they are unlikely to be *exactly* the same since there is a degree of randomness involved).

Table 3.8 – Long-Term Results

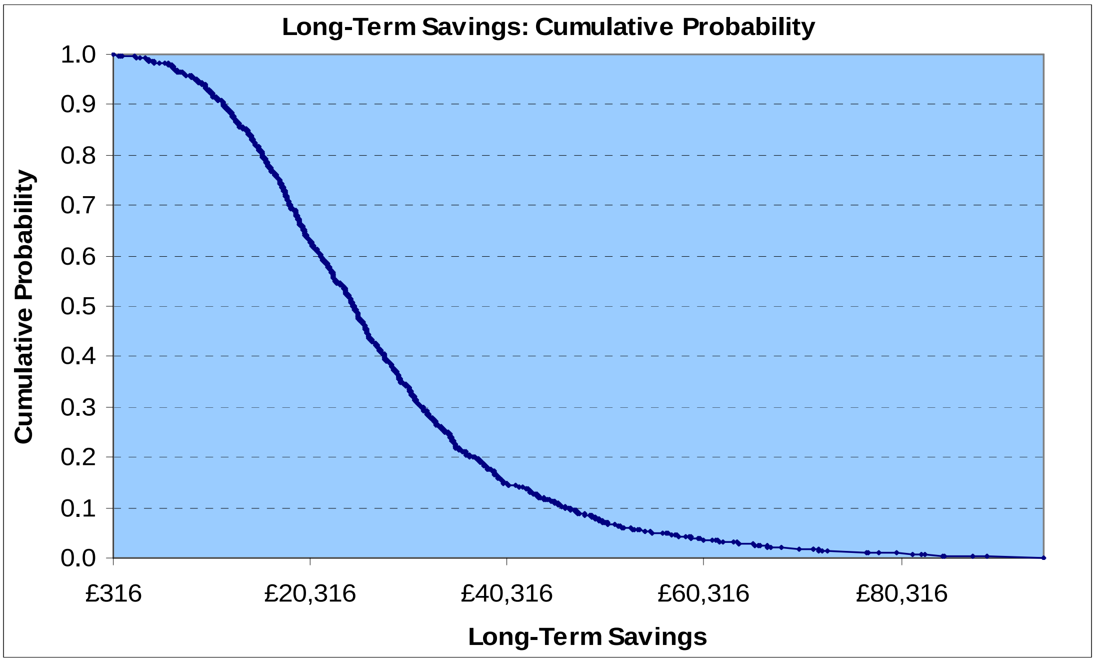
Item	Value
Maximum savings	£94,793.00
Mean (average) savings	£27,120.03
Minimum savings	£315.00
Standard deviation	£14,644.51
Prob. of +ve savings	100.0%

The above results show that the scope for possible long-term savings varies widely, with a total range of £94,793 and a standard deviation (the average variation from the mean) of £14,645. The probability of achieving positive savings is, in practice, likely to be 100%.

Long-Term Savings: cumulative probability graph

In themselves the results shown in table 3.8 do not tell us very much about system variability. The cumulative probability graph shown in figure 3.20 is a more useful tool.

Figure 3.20 – Cumulative probability graph showing long term-savings



The above graph can be used to determine the probability of achieving long-term savings *greater than or equal to* a given value e.g. If the x-axis value (long-term savings) is £20,000 and the corresponding y-axis value (cumulative probability) is 0.64, then there is a 0.64 (64%) chance that the long-term savings will be *greater than or equal to* £20,000

The graph can be used in conjunction with the *Probability of Savings >= 'x'* feature which takes a user-input figure and uses the graph data to return the probability of achieving savings greater than or equal to that value. Table 3.9 shows some examples.

Table 3.9 – Probability of Savings >= 'x' results

Value of x (£)	Event probability (%)
400	99.9
1,000	99.7
10,000	92.8
20,000	63.7
27,120 (mean)	42.1
50,000	7.2
80,000	0.9

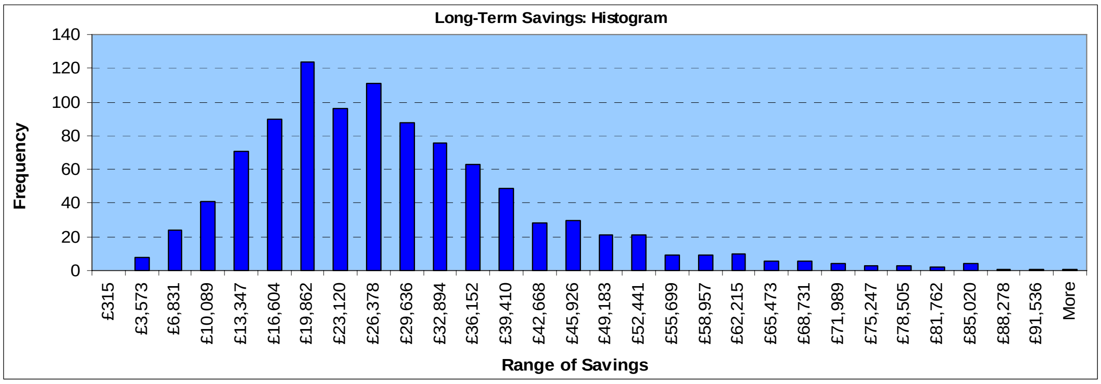
Table 3.9 shows that savings of several thousand pounds are highly likely e.g. savings greater than or equal to £1,000 have a very high probability of 99.7% (an almost certainty) whilst savings of £10,000 or greater have a probability of 91.7%, which is pretty good and should be enough to satisfy most people that savings are going to be at least equal to this amount. Higher savings show decreasing probabilities, with savings over £50,000 looking unlikely to occur given the low probabilities associated with them.

How these figures are interpreted will depend to a large extent on the mindset of the decision makers and how they perceive risk. People are often placed into one of three categories: risk averse, risk neutral or risk takers. The risk *averse* may be wary of anything that does not show a high probability of success whilst risk *takers* may be willing to accept less certainty. It is not possible to define clear boundaries between the three sorts of risk profiles and say exactly what level of risk is acceptable to each as people are all different, although of course everyone has a preference for *less* risk if at all possible. But it is important to highlight the fact that different people can perceive the same level of risk in different ways and hence the results shown on the previous page are open to some interpretation.

Long-Term Savings: histogram

Figure 3.21 shows the long-term savings histogram.

Figure 3.21 – Long-Term Savings histogram

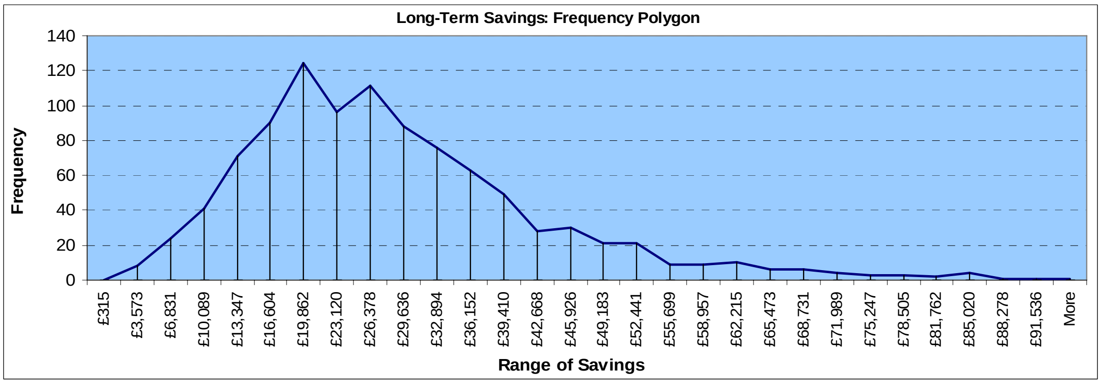


This shows the relative *frequency* of the long-term savings achieved in the last simulation. Note that the range of actual results theoretically extends from minus infinity to plus infinity for all real numbers and so in order to prevent having to plot every single result (up to 10,000) the figures are 'grouped' into classes (ranges). For example, suppose the classes increment in values of £1,000 (i.e. £0, £1000, £2000, £3000 etc) and that there are 5 results within the £1000-£2000 range, then those results would be placed into the £1000-£2000 range and the frequency within that range would be 5.

Long-Term Savings: frequency polygon

Figure 3.22 shows the long-term savings frequency polygon.

Figure 3.22 – Long-Term Savings frequency polygon



This chart displays the same data as the long-term savings histogram but presents the information in a different way. Points are placed on the graph that correspond to the mid-point of each class (range) and then a line is drawn from mid-point to mid-point in order to create a polygon. The vertical lines extending down to the x-axis represent the mid-point of each class range.

Both figures 3.21 and 3.22 can aid decision makers in getting a 'feel' for likely system performance. At a glance it can be seen that the bulk of the results are within the range of approximately £3,000 – £55,000. Few results are less than £3,000 and results of greater than £55,000 tend to tail off towards the £100,000 mark. From these charts it is easy to see that the likelihood of positive savings over 65 years are very high, with the actual figure most likely to be in the £3,000 - £55,000 range.

Pay-Back Period, Percentage of Demand Met and Average Yearly Savings

These three sections operate in a similar manner to that of the Long-Term Savings and so there is no need to reiterate the same points. It is still advisable to familiarise yourself with them and so it will be worthwhile experimenting with the available features. Help is available throughout all of the sections in the form of comments and pop-up dialog boxes.

Note that by default the bulk of the Monte Carlo simulation results are included in the Full Report.

3.7.5 Summary of Monte Carlo Simulation Results

Examining the available results in more detail would reveal the following:

Long-Term Savings

Probability of long-term savings >= £0 is 100.0%.

Probability of long-term savings >= £10,000 is 92.8%.

Probability of long-term savings >= £25,000 is 48.9%

Discussion: chances of achieving positive long-term savings in practice is almost certain. Savings of several thousand pounds appear very likely, although savings of several ten's of thousands of pounds would appear to be unlikely.

Pay-Back Period

Probability of pay-back within 65 years is 100.0%

Probability of pay-back within 25 years is 97.8%

Probability of pay-back within 10 years is 36.9%

Discussion: system is almost certain to pay for itself within 65 years. Chances of pay-back with 25 years are also very good but a pay-back period of less than 10 years appears to be unlikely.

Percentage of Demand Met

Probability of % demand met >= 100% is 0%

Probability of % demand met >= 60% is 66.4%

Probability of % demand met >= 50% is 92.6%

Discussion: Probability that 100% of non-potable demand can be met is zero. However, the results indicate that significant water savings are still likely to occur.

Average Yearly Savings

Probability of average yearly savings >= £0/yr is 100.0%

Probability of average yearly savings >= £250/yr is 77.4%

Probability of average yearly savings >= £1000/yr is 2.7%

Discussion: chances of achieving positive yearly savings in practice are almost certain. Savings of several hundred pounds per year appear very likely, although savings greater than £1000 per year would appear to be very unlikely. This shows that one of the key design criteria can almost certainly be met – that the school can cover the necessary maintenance costs out of the reduction in mains water bills.

This completes the Monte Carlo simulation tutorial. The next tutorial investigates the results obtained thus far and compares them to the criteria established in tutorial 1 (the Goal and Scope definition).

3.8 Tutorial 8: Assess Results and Make a Decision

3.8.1 Compare Analysis Results with RWH System Criteria

Whether the predicted performance of the rainwater harvesting system is deemed satisfactory or not will depend on the criteria used to judge the system. Criteria will vary from case to case although some, such as long-term savings, are likely to be universal. For the tutorial RWH system the client was a Local Authority and so, whilst financial issues are important to them, they also have an obligation to take a wider range of issues into account e.g. social and environmental. The criteria were broadly set out in tutorial 1: Goal and Scope Definition. Table 3.10 summarises these criteria and comments on whether or not they are likely to be met based on the analysis results obtained.

Table 3.10 – Criteria used to judge performance of the tutorial RWH system

Criteria	Expected Value (if applicable)	OK?	Comments
Capital cost does not exceed £20,000	£13,500	Yes	Anticipated capital cost is within allocated budget
School to pay own maintenance costs	£244/yr on average	Yes	Analysis shows that yearly savings are highly likely to cover maintenance costs
Save money in the long-term/risk of financial loss	£22,700 over 65 years	Yes	MC* simulation showed a wide range of possible savings but probability of positive savings is very high at an estimated 100%. Results acceptable
Short pay-back period preferred	12 years	Yes	MC* simulation showed pay-back period ranged between 6yrs and 60yrs. Chance of pay-back in 65 years = 100%. Results acceptable
Help conserve water resources/reduce reliance of mains water	67.8% demand met by harvested water	Yes	MC* simulation showed the % of demand met ranged between 42-91%. Results acceptable
Health and safety risks	-	Yes	General consensus that RWH systems are safe. UV unit included to minimise risk of infection
RWH system must be easy to install and maintain	-	Yes	Purchase proprietary system from established supplier. Undertake yearly maintenance contract with supplier

*MC = Monte Carlo

RWH System Performance Acceptable?

All of the criteria were met satisfactorily and the RWH system was installed as part of the initial construction phase of the school.

Even if some of the criteria had not been met, this would not necessarily have meant that the RWH system would not have been installed. If it performed well on a number of other criteria then it may still have been worth implementing e.g. if there was a long pay-back period but over 65 years significant savings would be seen then there would still be benefits to proceeding with the installation.

This concludes the Assess Results tutorial.

3.9 Tutorial 9: Printing System Reports

RainCycle Advanced has two types of automatically generated reports: Basic and Full. Both reports are accessed from the System Map screen and both types have a similar layout. The left-hand side of the screen contains the report itself and it is this section that will be printed. The green right-hand side of the screen contains further information about the report, such as which module each piece of information comes from. You can access the relevant modules directly by clicking on any underlined blue text e.g. clicking on the Project Details module text opens that module. Anything on the green right-hand side of the screen will not be printed as part of the report.

Basic Report

The basic report consists of the following items:

- Title page
- Project details (company and customer details, project notes)
- System and whole life cost details
- Maintenance schedule and associated costs
- Analysis runtime (in years)
- Yearly and long-term hydraulic results
- Average per-year cost results
- Long-term cost results

The basic report does not take into account the fact that the variable parameters can have more than one value and so the report is based on the currently selected parameter values (see the Analyse System module, Long-Term Analysis. The figures currently displayed in the Summary of Active Parameters table are the ones used in the report). If the basic report is to be printed then it is worthwhile double checking the figures in this table to ensure that they are the ones you want to use. Whenever any changes are made to the application the basic report will automatically update so there is no need to edit the actual report.

There are also no scenario modelling, sensitivity analysis or Monte Carlo simulation results. For these it is necessary to refer to the full report.

If you have not already done so, from the System Map screen select the Basic Report module. Have a look at the report in order to familiarise yourself with the layout and the information presented.

Full Report

The full report consists of the following items:

- Title page
- Project details (company and customer details, project notes)
- Project overview
- System and whole life cost details
- Maintenance schedule and associated costs
- Analysis runtime (in years)
- Yearly and long-term hydraulic results
- Average per-year cost results
- Long-term cost results
- Scenario modelling results
- Sensitivity analysis results
- Monte Carlo Simulation results

The layout of the full report is essentially the same as for the basic report. Note that there are three additional options on the right-hand side of the screen: “include scenario modelling results?”, “include sensitivity analysis results?” and “Include Monte Carlo results?”. Selecting/deselecting these checkboxes adds/removes the corresponding sections.

It should be noted that for the above items, the report displays the results from the last time they were run. If any changes have been made that affect them then it will be necessary to re-run the analysis in order to update the tables and graphs displayed in the report preview.

Printing the Reports

A full systems analysis was conducted as part of tutorials 1-7 and so in order to present all of the results obtained it would be necessary to print a copy of the full report. From the System Map screen, select the Full Report module. Have a look at the report in order to familiarise yourself with the layout and the information presented. You can print the report if you wish, although this is not strictly necessary. Print formatting has already been set up and so all that is required is to tell Excel to print the report. Either click the print icon on the toolbar or go to the File menu and select Print.

This concludes the tutorial chapter which has covered the primary features of the RainCycle Advanced application. The program also contains a number of secondary features and these are discussed in the next chapter.

4.0 Other Features

4.1 Detailed Results and Graphs

More detailed analysis results are available, if required. These can be accessed by clicking the button labelled “Detailed Results”, located in the top right-hand corner of the long-term analysis screen, Analyse System module. Clicking this button brings up a dialog box that allows the user to choose between detailed hydraulic results or detailed financial results. Whichever option is chosen, the user can view the various graphs and tables by clicking on the relevant navigation tabs located near the top of the screen, as shown in figure 4.1. The word ‘Viewing’ will appear above the last tab clicked, indicating which results section is currently active.

Figure 4.1 – Navigation tabs in the detailed hydraulic results sub-module

The hydraulic results are displayed in table and graph form and all data refers to one year of results (all years used in the hydraulic simulation are assumed to be the same). The financial results are displayed in tabular form only and the cost calculations are carried out independently for each year that the analysis is run for.

An arrow next to a table (**<**) containing variable parameter values indicates which value is currently selected for the analysis. All the graphs in the hydraulic results module have two display modes: daily values or cumulative values for one year. To switch between the different modes for each set of graphs, click the button labelled “Toggle Graphs”.

It is possible to copy/paste the results tables and graphs into another Excel workbook or Windows application e.g. MS Word.

4.1.1 Detailed Hydraulic Results

The detailed hydraulic results sub-module consists of the following sections:

Parameter	Tables	Graphs
Rainfall Profiles	Summary of yearly rainfall data for above average, average and below average rainfall depths	Daily and cumulative above average, average and below average rainfall depths.
Catchment Surface	Summary of catchment surface data: catchment surface area, first-flush volume, high, expected and low runoff coefficients	Daily and cumulative rainfall volume falling on catchment surface
	Summary of rainfall/runoff results: yearly volume of water falling on catchment surface, effective runoff volume and runoff losses	Daily and cumulative effective runoff volume
		Daily and cumulative runoff losses
Rainwater Filter	High, expected and low filter coefficients	Daily and cumulative volume of water entering filter
	Summary of rainwater filter results: yearly volume of water passed to filter, volume of water passed to tank and volume of water lost from filter	Daily and cumulative volume of water to tank from filter
		Daily and cumulative filter losses
Additional Inputs	Summary of above average, average and below average yearly additional inputs	Daily and cumulative above average, average and below average additional inputs
Storage Tank	Summary of storage tank details: storage volume and number of drain-down intervals	Daily and cumulative volume of water entering tank
		Daily volume of water in tank
	Summary of storage tank simulation results: volume of water entering tank, overflow, withdrawal, total number of days per year tank is empty and longest consecutive number of days per year tank is empty	Days when drain-down occurs
		Daily and cumulative overflow from tank
Pump	Summary of pump details: power rating and pumping capacity	Daily and cumulative operating time
	Summary of pump results: operating time, total power usage and total energy usage	Daily and cumulative power usage
		Daily and cumulative energy usage
UV Unit	Power rating and daily operating time of UV unit	Daily and cumulative UV unit operating time
	Summary of UV treatment results: UV unit operating time, total power usage and total energy usage	Daily and cumulative UV unit power usage
		Daily and cumulative UV unit energy usage
Water Demand	Summary of above average, average and below average yearly water demand	Daily and cumulative water demand
	Summary of water demand results: total yearly water demand used in simulation, average daily water demand, water supplied and shortfall	Daily and cumulative water supply from tank
		Daily and cumulative shortfall (mains top-up required)
Water Sources	Summary of water sources results: total input to tank, rainwater input to tank and additional inputs to tank (if any)	Daily and cumulative total input to tank and sources of water
		Daily and cumulative sources of water supplied to end users

4.1.2 Detailed Financial Results

The detailed financial results sub-module consists of the following sections:

Parameter	Tables
Whole Life Cost (WLC) Summary	Summary of WLC data at current prices: capital and decommissioning costs, discount rates, electricity costs, mains water costs, disposal costs and number of active maintenance items
	Summary of WLC results (at Present Value). Cost items include: capital, maintenance, decommissioning, pump operation, UV unit operation, mains top-up, total WLC of RWH system, total WLC of equivalent mains-only system and RWH system savings (if any)
	WLCs Data Table: shows detailed year-by-year results for financial calculations
Maintenance Costs	No. of maintenance items selected (active maintenance items)
	Summary of maintenance activities and associated values (at Present Value). A list of all maintenance activities, frequencies, total cumulative cost over whole analysis runtime and % of maintenance costs. Also displays the total cost (at Present Value) of all maintenance activities over the whole analysis runtime
	Maintenance costs data table: a detailed year-by-year breakdown of all maintenance activities and their yearly costs (at Present Value)
Water Costs	Summary of water cost data: mains water costs and water disposal costs (if any)
	Summary of water demand data: above average, average and below average yearly water demand figures
	Summary of long-term water supply and demand: total water demand over 'x' years; water supplied from RWH system over 'x' years and percentage of demand met by RWH system; shortfall from RWH system
	RWH system and mains-only system cost comparisons: WLC of RWH system, amount of water supplied by RWH system over 'x' years, cost of harvested water on a per m^3 basis, WLC of equivalent mains-only system and cost of mains-only water on a per m^3 basis

Note: there are no graphs with the detailed financial results. All results take into account the selected discount rate

Appendix 1

Discount Rate Explained

The *discount rate* is a financial accounting technique commonly used by businesses to discount money with time in order to help make financial decisions that span several years. Many businesses often use different discount rates depending on their aims and objectives, perceived investment risk, project timescale, current and predicted future financial criteria (e.g. interest rates) and sometimes the personal opinions and experiences of the key decision makers. To some extent the selection of an appropriate discount rate is arbitrary – there is no scientific method for selecting the “right” value.

The process of selecting the most appropriate discount rate is rather complex and thus we will not go into the details of it. Most people consider the discount rate to be related to opportunity cost of investing capital. In other words, if an investor considers receiving £100 today as equivalent to receiving £112 one year from today, then the discount rate is 12% for that investor. The discount rate is usually much higher than the interest rate that you would get from the bank since it includes risk, cost of capital, government policies, and other business factors.

It should be noted that in order to use RainCycle it is not strictly necessary to take the discount rate into account. It is likely to be most applicable to businesses or large organisations that need to undertake proper financial accounting of future cash flows. It may not be particularly useful to people simply wanting a small domestic system. If this is the case, all discount rate fields can be set to zero, resulting in all future costs simply being reported back at their *equivalent current price*s i.e. what those items would cost right now.

Whole Life Costing, Net Present Value and Discount Rates

Whole Life Costing is about identifying future costs and referring them back to present day costs using standard accounting techniques such as Present Value (PV). Different methodologies for discounting future costs exist, but PV is the simplest and most commonly used discounting method available and is appropriate for application to rainwater harvesting (RWH) systems which may have different time patterns of expenditure e.g. irregular maintenance items. It should be noted that discounting costs to a PV has limitations and is sensitive to discount rates and assumptions of future costs and the timing of these costs.

Present Value (PV) is defined by MAFF (1999) as: *"The value of a stream of benefits or costs when discounted back to the present time"*. It can be thought of as the sum of money that needs to be spent *today* in order to meet all future costs as and when they arise throughout a system's lifetime. The formula for calculating the *Net* PV is:

$$NPV = \sum_{t=0}^{t=N} Ct \,/\, (1+r/100)^t$$

Where: NPV = Net Present Value
N = time horizon in years
C_t = total monetary costs in year t
r = discount rate in %

The higher the discount rate, the less impact future costs will have on the Net Present Value (NPV) – see figure A1 for an example. If the discount rate is set to zero then all future costs will be returned at their equivalent current prices. Currently the UK Treasury is recommending that a discount rate of 3.5% be used (2005).

Figure A1 – graph showing effect of discount rate on Net Present Value

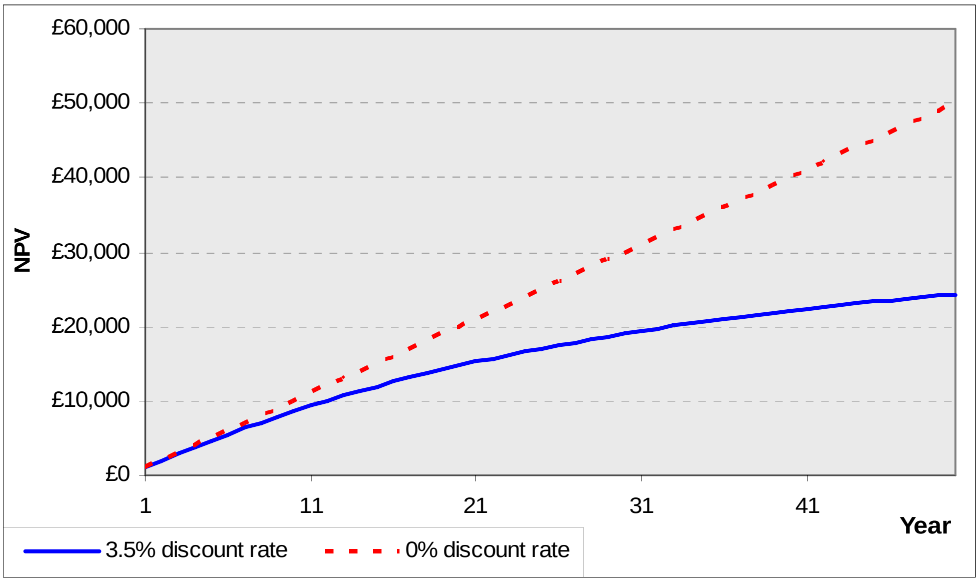


Figure A1 shows the effect of applying a discount rate of 3.5% per year for 50 years to a system that costs £1000/yr to run. The cumulative cost of the 0% discount rate scenario was calculated simply by summing the running costs for 50 years i.e. 50 x £1000/yr = £50,000. For the discounted cumulative cost, the aforementioned NPV formula was used to apply a discount rate of 3.5% per year. As the results show, this makes future costs appear to have less impact and the cumulative discounted cost in this case is equal to £24,276 over 50 years.

Appendix 2

Typical Water Uses and Associated Volumes

Each person in the UK currently uses about 150 litres of water per day, with approximately one third (50 litres) of this being used to flush the W.C. The average UK per capita water demand is predicted to rise to 165 litres per person per day by early 2020.

In a typical home the W.C. is the appliance that uses the most water, with the bath and shower forming the next largest contributions respectively. Other common end-uses can include: washing machine, wash basin, drinking, food preparation, garden irrigation and car washing.

Harvested rainwater is not normally used for potable purposes. Even though it is technically possible to treat collected rainwater to any quality required, it is often not cost effective to do so. Harvested rainwater is usually reserved for non-potable uses, such as toilet/urinal flushing, garden irrigation, washing machines and vehicle washing. In well designed and maintained RWH systems that have adequate particle filtration, the quality of water should be good enough for these end-uses without requiring any further treatment, such as disinfection.

Tables A2.1 and A2.2 show a variety of water uses and a typical range of volumes associated with each (figures are for the UK).

Table A2.1 – Non-potable end uses

Application	Volume (litres)	Comments
W.C. flushing	4.3-14.5/flush (mean = 9)	Average daily domestic usage is 43 litres/person/day. Modern 'standard' WC's use 6 litres/flush
Urinal flushing	7-9/flush	2 flushes per hour is not uncommon
Garden irrigation	1000-1200/ irrigation session	Garden irrigation has been estimated to occur once every five days in the May to August period.
Garden sprinkler	10/min	Usage varies with season
Washing machine	40-50/load	Average per person per day usage is 13-30 litres
Vehicle washing	Up to 300/wash	Assumes a hose pipe is used.

W.C. = water closet (toilet)

Table A2.2 – Potable end uses

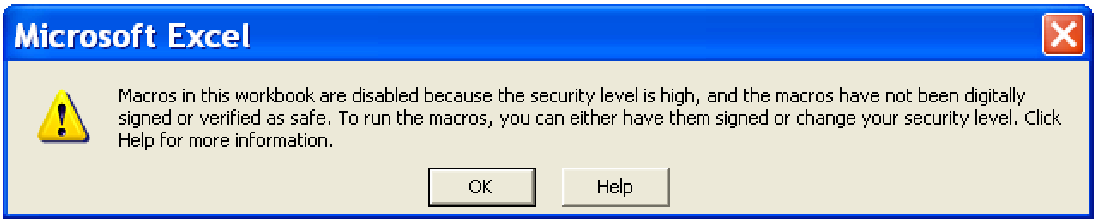
Application	Volume (litres)	Comments
Bath	Up to 80/bath	
Shower	Up to 35/shower	
Power shower	Up to 112/shower	Assumes showering lasts for 8 minutes
Wash basin	2-13/person/day	
Drinking/cooking	5-25/person/day	
Dishwasher	20-50/load	Average per person per day figure is 9-45 litres
Other uses	18-50/person/day	Non-specified uses

Both tables demonstrate that the 'average' water usage per person per day can vary significantly. However, this can be taken into account by using RainCycle's ability to model above average, average and below average daily water demand profiles.

Appendix 3

Trouble Shooting

1) None of RainCycle's functions appear to be working and I get the error message shown below when I try to use the application.



In order for RainCycle to function correctly, you must have Macros enabled. This will allow Excel to run the computer code associated with RainCycle (the code is contained within Excel's Visual Basic for Applications [VBA] module). The code only interacts with the RainCycle application itself; it will not affect any other spreadsheets or other computer programs that may be running, nor will it affect the PC in any way. To enable Macros, go to: Tools > Macro > Security. Change the security setting to *low* or *medium* (medium is recommended) and click OK. You will have to close the RainCycle application and then reopen it in order for the changes to take effect.

2) The individual worksheets do not fit onto one screen, or they do but the text and other features are unclear because they are too small.

The suggested screen resolution for running RainCycle is 1024x768 pixels. If the resolution is lower than this then the individual worksheets will not fit within the screen space available and it will be necessary to scroll the display in order to access all the features. If the resolution is higher, the individual worksheets will fit on the screen but the text and other features may be too small to be readable or usable. If this is the case you should change the resolution to the recommended 1024x768 pixels. To do this, place the mouse pointer on the desktop and click the right mouse button. A menu will appear. Select: Properties > Settings. In the dialog box that appears, there will be a section labelled 'Screen Resolution'. You can change the resolution to the recommended 1024x768 here, if you so wish.

Also check that Excel's Zoom function is set to the correct value for use with RainCycle. Go to: View > Zoom and make sure that the magnification is set to 100%.

3) Whenever I try to copy/paste data from RainCycle to another workbook it copies all the cell formatting and the formulas. All I want are the actual figures!

In order to copy only the figures, select the range you want and copy it into memory. Then, on the destination worksheet, right-click on the target cell and from the menu that appears select *Paste Special*. Another menu will appear. Select either *Values* (if you just want the actual values) or *Values and number formats* if you also want to retain cell formatting.

Frequently Asked Questions

Q) Can RainCycle be used to model greywater or combined rainwater/greywater systems?

A) RainCycle can model the *hydraulics* and *whole life costs* of such systems by using the Additional Inputs module to take into account the inflow of greywater to the storage tank and the maintenance planner in the WLC module to take into account the maintenance requirements. However, it should be noted that there are additional water quality issues with greywater systems and that RainCycle does not explicitly model these.

Q) I don't understand what the discount rate is all about. Help!

A) The discount rate is explained in appendix 1. However, the concept is not always easy to grasp and the term itself is not widely known outside of accounting circles. In order to use RainCycle it is not strictly necessary to take the discount rate into account. It is likely to be most applicable to businesses or large organisations that need to undertake proper financial accounting of future cash flows. It may not be particularly useful to people simply wanting a small domestic system. If this is the case, all discount rate fields can be set to zero, resulting in all future costs simply being reported back at their *equivalent current price*s i.e. what those items cost right now.

Q) Why doesn't the financial analysis take into account the mains supply standing charge?

A) Any standing charge costs are assumed to apply equally to both the RWH system (due to the presence of mains back-up) and an equivalent mains-only system. Because the standing charge applies equally to both systems (i.e. it costs the same) then it makes no overall difference to the comparative study and so was left out of the analysis.

Q) When simulating a system, is it necessary to utilise all of RainCycle's features, as demonstrated in chapter 3 of the manual (the tutorial chapter)?

A) No. The chapter 3 tutorials demonstrate how to use all of RainCycle's main features and highlight its powerful analytical functions. However, the level of detail that you go into when performing your own analysis is entirely up to you. A basic simulation only requires a limited amount of data, namely:

- One years worth of monthly rainfall figures for the catchment under study.
- Catchment surface area and runoff coefficient.
- Rainwater filter coefficient.
- Volume of rainwater storage tank.
- Expected daily water demand for one year.
- Some cost data, namely: RWH system capital cost and mains water cost.

This basic simulation would not take into account system running and maintenance costs and assumes a zero discount rate. It will also not be possible to carry out any scenario modelling or perform a sensitivity analysis since it does not include more than one set of values for the variable parameters. However, it will be accurate enough to give a good indication of potential financial savings and could form the basis of a more in-depth analysis, if this was justified.

Alternatively a basic analysis can be performed using RainCycle Standard©, a simplified version of the full application which is supplied as part of the RainCycle license.

Q) How reliable are the results?

A) As with any computer simulation, the accuracy of the results depends to a large extent on the accuracy of the information input by the user. As always, the acronym GIGO (garbage in, garbage out) applies. Therefore, the data input into the application should be as accurate and applicable to the catchment area/system under study as possible. Further, any computer simulation is only a representation of the real world. Simulations are useful tools but they will never be 100% accurate due to fundamental limits in human knowledge. They are unlikely to include any unusual site-specific criteria nor be able to model all the 'fine details'. However, this particular modelling tool includes all the major components that are applicable to rainwater harvesting systems and is based on current best practice methods and state-of-the-art research. Hence the results, although they should not be treated as definitive, will be accurate enough to give a good indication of likely system performance and whole life costs.

Q) Why didn't you include feature 'X' in RainCycle?

A) We tried to include all the major components employed by the majority of rainwater harvesting systems, although it is acknowledged that some may have uncommon site specific requirements and so cannot be modelled explicitly with the application. However, even in these cases there should be enough flexibility in the software to be able to model *most* of the system components and for the results to still be useful in predicting the hydraulic performance and whole life costs.

If you would like to see any specific feature in future versions, then drop us a line at support@sudsolutions.com and if the idea has merit then we will consider including it in future versions of the software.

Appendix 4

Other RainCycle Advanced Case Studies

The following RainCycle Advanced case studies are theoretical situations in which the installation of a RWH system is under consideration. Note that even though the studies are theoretical they do represent realistic scenarios.

A4.1 Case Study 1 – Typical Domestic System

Scenario: typical domestic dwelling with 2 adults.

Proposed harvested water use: WC flushing and washing machine.

Assessment level: basic assessment to determine financial feasibility of a RWH system. Assess expected scenario only i.e. use only average/expected parameter values.

Selected analysis runtime: 25 years

Catchment parameters

Parameter	Value	Comment
Location	-	West Yorkshire region
Average annual rainfall	885mm/yr	Use monthly average rainfall values (Met. Office published data)
Building type	-	Domestic dwelling
Catchment surface area	$50m^2$	Catchment area is building roof
Runoff coefficient	0.85	Pitched roof tiles
Rainwater filter coefficient	0.90	None
Additional inputs	0	No additional inputs

RWH system parameters

Parameter	Value	Comment
Power rating of pump	0.8kW	None
Pumping capacity of pump	60 litres/min	None
UV unit power rating	-	No UV unit

Maintenance/operating costs

Parameter	Value	Comment
Mains water cost	£1.92/m^3	None
Cost of electricity	7p/kWhr	None
Discount rate	0%	Not considered relevant
Maintenance/operating costs	£500 every 7 years	To cover pump replacement

Daily water demand for one year:

Using figures from appendix 2:

WC flushing: 43 litres/person/day. 2 people = 43 x 2 = 86 litres/day

Washing machine: 30 litres/person/day. 2 people = 30 x 2 = 60 litres/day

Total daily water demand: 86 + 60 = 146 litres/day = **0.146m^3/day**.

It was assumed that water demand was the same for all days of the year.

Assess System

Optimise Tank Size

Optimise Tank Size analysis revealed that the maximum percentage of demand that could be met was 64% with a tank size of $1m^3$. Therefore the limiting factor was the amount of water available and so increasing the tank size above $1m^3$ would have little (if any) benefit.

Optimise Savings

The following tank size vs. capital cost data was used for the Optimise Savings analysis:

Tank Size (m^3)	Capital Cost (£)
0.500	1,200
1.200	1,500
3.000	2,100
6.000	2,500
6.500	2,800

Source: various RWH system suppliers

Review Optimise Savings Results

Figure A4.1 shows the results from the Optimise Savings analysis.

Figure A4.1 – Results from Optimise Savings analysis

Latest Simulation Results (25 years)				
Tank Size (m^3)	Capital Cost	Savings over 25yrs	Pay-Back Period (yrs)	Demand Met (%)
0.500	£1,200	-£1,088	N/A	63.5
1.200	£1,500	-£1,388	N/A	63.5
3.000	£2,100	-£1,988	N/A	63.5
6.000	£2,500	-£2,388	N/A	63.5
6.500	£2,800	-£2,688	N/A	63.5

All tank sizes simulated showed a long-term loss. Looking at the % demand met, as expected there would be no benefit to having a tank greater than $1m^3$.

This basic analysis showed that none of the available tank sizes would be likely to show any financial savings within 25 years of operation and so the assessment was not taken any further i.e. the system was rejected outright.

A4.2 Case Study 2 – Another Typical Domestic System

Scenario: typical domestic dwelling with 2 adults and 2 children

Proposed harvested water use: WC flushing and washing machine. Garden irrigation and car washing during the summer months.

Assessment level: basic assessment to determine financial feasibility of a RWH system. Assess expected scenario only i.e. use only average/expected parameter values.

Selected analysis runtime: 25 years

Catchment parameters

Parameter	Value	Comment
Location	-	West Yorkshire region
Average annual rainfall	885mm/yr	Use monthly average rainfall values (Met. Office published data)
Building type	-	Domestic dwelling
Catchment surface area	$100m^2$	Catchment area is building roof
Runoff coefficient	0.85	Pitched roof tiles
Rainwater filter coefficient	0.90	None
Additional inputs	0	No additional inputs

RWH system parameters

Parameter	Value	Comment
Power rating of pump	0.8kW	None
Pumping capacity of pump	60 litres/min	None
UV unit power rating	-	No UV unit

Maintenance/operating costs

Parameter	Value	Comment
Mains water cost	£1.92/m^3	None
Cost of electricity	7p/kWhr	None
Discount rate	0%	Not considered relevant
Maintenance/operating costs	£500 every 7 years	To cover pump replacement

Daily water demand for one year:

Using figures from appendix 2, table A2.1:

WC flushing: 43 litres/person/day. 4 people = 43 x 4 = 172 litres/day

Washing machine: 30 litres/person/day. 4 people = 30 x 4 = 120 litres/day

Total daily water demand: 172 + 120= 292 litres/day = **0.292m^3/day**.

Account for seasonal variation in water demand

Assume garden irrigation occurs once per week during May to August period and uses 1000 litres per session. Assume that car washing also occurs once per week during the same period and uses 300 litres per wash.

Total additional usage = 1000 + 300 = 1300 litres = **1.3m^3 per week**.

Therefore, in the Water Demand module, for one day per week during May-August an additional 1.3m^3 was added to the daily water demand figures.

Total seasonal demand = 0.292 + 1.3 = **1.592m^3 once per week, May-August period**.

It was assumed the extra demand occurred on Sundays.

Assess System

Optimise Tank Size

Optimise Tank Size analysis revealed that the maximum percentage of demand that could be met was 53% with a tank size of 1m^3. Therefore the limiting factor was the amount of water available and so increasing the tank size above 1m^3 would have little (if any) benefit.

Optimise Savings

The following tank size vs. capital cost data was used for the Optimise Savings analysis:

Tank Size (m^3)	Capital Cost (£)
0.500	1,200
1.200	1,500
3.000	2,100
6.000	2,500
6.500	2,800

Source: various RWH system suppliers

Review Optimise Savings Results

Figure A4.2 shows the results from the Optimise Savings analysis.

Figure A4.2 – Results from Optimise Savings analysis

		Latest Simulation Results (25 years)		
Tank Size (m^3)	Capital Cost	Savings over 25yrs	Pay-Back Period (yrs)	Demand Met (%)
0.500	£1,200	£524	21	52.6
1.200	£1,500	£224	23	52.6
3.000	£2,100	-£376	N/A	52.6
6.000	£2,500	-£776	N/A	52.6
6.500	£2,800	-£1,076	N/A	52.6

The Optimise Savings analysis showed that there were two tank sizes with a potential long-term profit. The best was the 0.5m^3 tank which was predicted to save £524 over 25 years and had a pay-back period of 21 years, which is fairly typical for a domestic system at the present time. % demand met was also good for a domestic system at 53% of the predicted demand.

The 0.5m^3 tank was deemed to give acceptable results and so the data for this tank was input into the Storage Tank module (tank size) and WLC Details module (capital costs) and then the results in the Analyse System module examined. Figures A4.3 and A4.4 show the cost comparison graphs for both the long-term and average per-year analyses for this system.

Figure A4.3 – Cumulative long-term analysis cost comparison graph

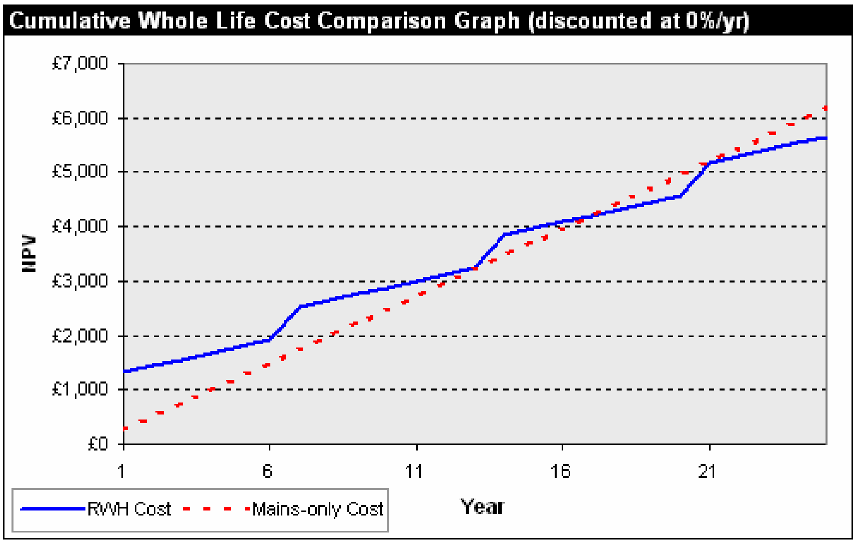
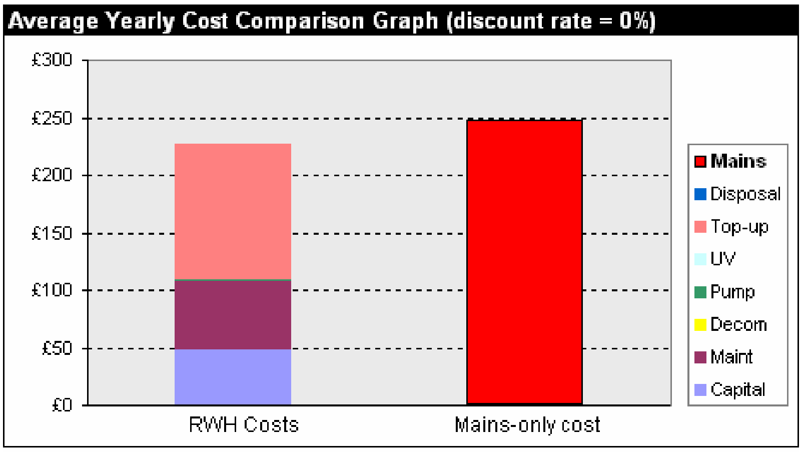


Figure A4.4 – Average yearly cost comparison graph



Comparative Cost of Water Supplied per m^3	
Average cost of mains water	£1.92
Average cost of harvested water	£1.76

The results indicated that the RWH system could potentially save money, although the expected running costs of the system would be close to that of a mains-only supply. Therefore the system is feasible, but there would be some inherent monetary risk and an overall financial loss would be a real possibility. If this were a real assessment it would be advisable to model a number of scenarios to investigate this risk further e.g. best, expected and worst-case scenarios.

A4.3 Case Study 3 – Hotel System

Scenario: Typical medium sized hotel

Proposed harvested water use: WC flushing and washing machines

Assessment level: detailed assessment to determine financial feasibility of a RWH system, investigate system variability under a range of scenarios (best, expected and worst case) and also conduct a sensitivity analysis to identify areas of weakness/potential improvement.

Selected analysis runtime: 50 years

Average/expected catchment parameters

Parameter	Value	Comment
Location	-	West Yorkshire region
Average annual rainfall	885mm/yr	Use monthly average rainfall values (Met. Office published data)
Building type	-	Medium sized hotel
Catchment surface area	$2000m^2$	Catchment area is building roof
Expected runoff coefficient	0.55	Flat roof with smooth surface
Expected rainwater filter coefficient	0.90	None
Average additional inputs	0	No additional inputs

System parameters

Parameter	Value	Comment
Power rating of pump	1.4kW	Multi-storey building. Pump needs sufficient power to reach top floor
Pumping capacity of pump	55 litres/min	None
UV unit power rating	80W	Health and safety of guests is paramount, so install UV system

Average/expected maintenance & operating costs

Parameter	Value	Comment
Expected mains water cost	£1.92/m^3	None
Expected cost of electricity	5.5p/kWhr	None
Expected discount rate	3.5%	Business, so future cash flows are important
General maintenance contract	£250/year	Maintenance contract is with RWH system supplier
UV unit costs	£110	Replace UV lamp and UV unit in-line water filters once per year

Average daily water demand for one year:

Hotel has 20 en-suite rooms, 10 single and 10 double. Average occupancy throughout the year amounts to 70% capacity (7 single rooms and 7 double rooms occupied at any one time). There are 5 permanent members of staff.

Average number of people in the hotel at any one time: 1 x 7 (single rooms) + 2 x 7 (double rooms) + 5 (staff) = 26.

Using figures from appendix 2, table A2.1:

WC flushing: 43 litres/person/day. 26 people = 43 x 26 = 1,118 litres/day

Washing machine: Average of 15 loads per day to wash bedding, towels, staff uniforms etc. 30 litres per load. 15 x 30 = 450 litres/day

Total daily water demand: 1,118 + 450 = 1,568 litres/day = **1.568m^3/day**.

Assess System

Optimise Tank Size

Optimise Tank Size analysis revealed that, using the average water demand figures, 100% of demand could be met with a small (approximately 2m^3) tank. Therefore, the decision was made to increase the water usage from the system. The hotel has a large landscaped garden which requires watering during the summer months. It is estimated that irrigation takes place once per week during the May-August period and that approximately 2m^3 are used to water the garden during every irrigation session.

Therefore, once per week during May-August period, water demand is **3.568m^3**.

Running the Optimise Tank Size routine again with the new water demand figures revealed that 100% demand could be met with a tank size of 5m^3.

Optimise Savings

The following tank size vs. capital cost data were used for the Optimise Savings analysis:

Tank Size (m^3)	Capital Cost (£)
0.500	1,200
1.200	1,500
3.000	2,100
6.000	2,500
6.500	2,800

Source: various RWH system suppliers

Review Optimise Savings Results

Figure A4.5 shows the results from the Optimise Savings analysis.

Figure A4.5 – Results from Optimise Savings analysis

		Latest Simulation Results (50 years)		
Tank Size (m^3)	Capital Cost	Savings over 50yrs	Pay-Back Period (yrs)	Demand Met (%)
6.000	£2,500	£15,745	3	100.0
3.000	£2,100	£15,701	3	98.4
6.500	£2,800	£15,445	4	100.0
1.200	£1,500	£8,994	4	72.2
0.500	£1,200	-£2,471	N/A	30.1

The Optimise Savings analysis showed that the 6m^3 had the best long-term savings, showing a return of £15,745 over 50 years (with future costs discounted at 3.5% per year). Pay-back period was joint best with the 3m^3 tank at 3 years and the % demand met was predicted to be 100%. Therefore the 6m^3 tank was deemed to be the optimum choice out of those modelled and was taken forward to assessment stage 3: detailed analysis.

Detailed Analysis

Investigation of 3 scenarios (best, expected and worst) was required as part of the analysis and so above average/high and below average/low values were obtained for the variable parameters.

Variable parameter values for best case scenario

Parameter	High/above average value	Comment
Above average rainfall	1106mm/yr	Average rainfall +25%
High runoff coefficient	0.60	See table 2.1
High rainwater filter coefficient	0.92	Anticipated peak filter performance
Above average additional inputs	0	No additional inputs
High mains water cost	£2.27	Expected value +18%
Low cost of electricity	5.5p/kWhr	Same as expected scenario
Low discount rate	2.0%	None
General maintenance contract	£250/yr	Same as expected scenario
UV unit costs	£110/yr	Same as expected scenario
Above average water demand	1.882m^3/day (4.282m^3/Sunday during May-August period)	Average water demand +20%

Variable parameter values for worst-case scenario

Parameter	High/above average value	Comment
Below average rainfall	663mm/yr	Average rainfall -25%
Low runoff coefficient	0.50	See table 2.1
Low rainwater filter coefficient	0.85	In case no maintenance conducted
Below average additional inputs	0	No additional inputs
Low mains water cost	£1.92	Same as expected value
High cost of electricity	6.9p/kWhr	Expected value + 25%
Discount rate	6.0%	Previous UK discount rate
General maintenance contract	£250/yr	Same as expected scenario
UV unit costs	£220/year	x2 UV lamp replacement per year
Below average water demand	1.254m^3/day (2.854m^3/Sunday during May-August period)	Average water demand -20%

Detailed Simulation Results

Figures A4.6 and A4.7 show the cost comparison graphs for both the long- and short-term (average per-year) simulations for this system using the average/expected parameter values.

Figure A4.6 - Cumulative long-term analysis cost comparison graph

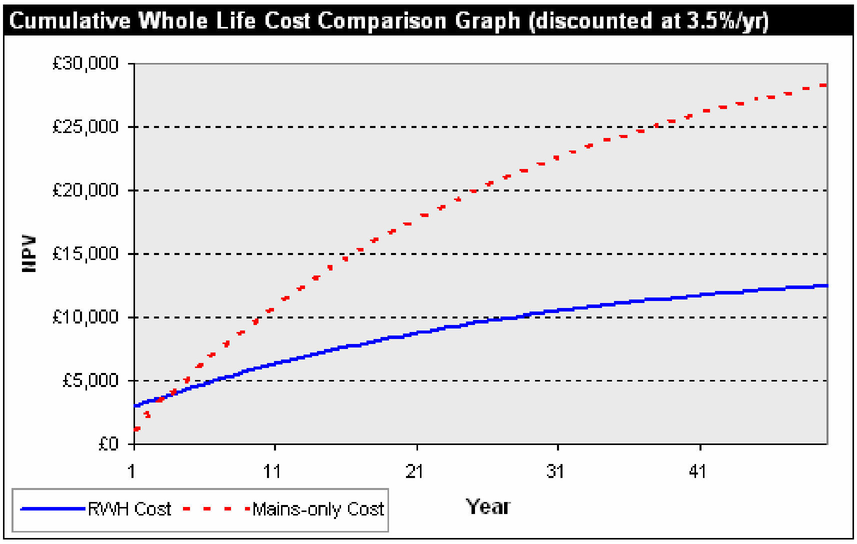
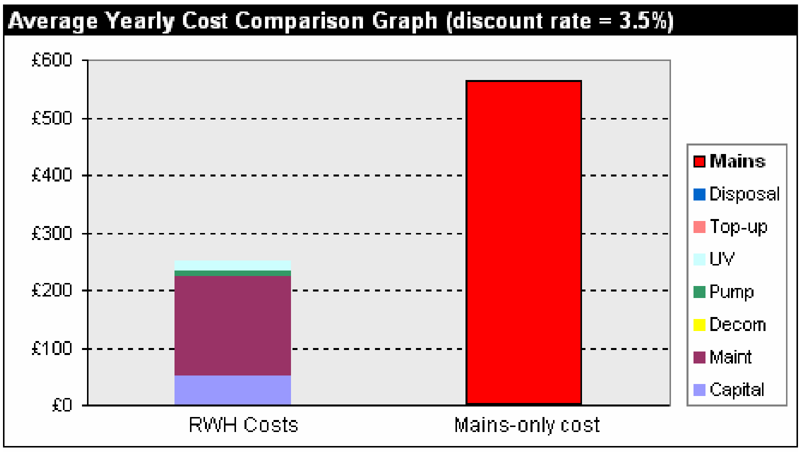


Figure A4.7 - Average yearly cost comparison graph



Comparative Cost of Water Supplied per m³	
Average cost of mains water	£0.93
Average cost of harvested water	£0.41

The results as this stage indicate that the proposed RWH system has a short pay-back time (3 years), that supply and demand are well balanced (demand met was predicted as 100%), that substantial long-term savings are possible (£15,745 over 50 years) and that the cost of water supplied from the RWH system would be less than half of that from the mains (£0.41/m^3 from the RWH system as opposed to £0.93/m^3 from the mains supply). The average per-year saving is not shown here but it was predicted as £315 per year.

By all indications the proposed system should almost certainly be a worthwhile investment. However, to remove any remaining doubt regarding financial viability, two more scenarios were modelled – best case and worst case (see earlier for the selected best and worst case variable parameter values).

Table A4.1 shows a summary of the main results obtained from the scenario modelling exercise. The expected scenario results are also included for completeness.

Table A4.1 – Results from scenario modelling for hotel case study

	Long-term analysis results			*Average per-year results*		
Scenario Description	**Demand Met (%)**	**Pay-Back Period (yrs)**	**Savings (£/50yrs)**	**RWH Cost (£/yr)**	**Mains-only cost (£/yr)**	**Savings (£/yr)**
Best case	100	2	37,130	316	1,059	742
Expected	100	3	15,742	250	565	314
Worst case	97	8	3,671	238	311	73

The scenario modelling results showed that even under the worst possible assumptions the RWH system performance was still good compared to a mains only system and that long-term savings would still be observed.

Sensitivity Analysis

The final part of assessment was to perform a sensitivity analysis (no Monte Carlo simulation was run), with the aim of identifying areas of risk/potential improvement. The following bullet points summarise the key findings from the sensitivity analysis (actual tables and graphs are not shown because it is only the main findings that are of interest).

For Savings over 50yrs

- RWH system savings over 50 years only showed any real sensitivity to changes in 4 parameters: discount rate (+£5,843 for best case, -£5,688 for worst case, £11,531 total change), daily water demand (+£4,633 for best case, -£5,590 for worst case, £10,222 total change), mains water cost (+£5,152 best case, £0 worst case, £5,152 total change) and rainfall profile (+£0 best case, -£1,810 worst case, £1,810 total change). Changes due to other parameters were negligible compared to these four
- Conclusion: given the above results, the following course of action would be advisable: ensure that the selected discount rate is appropriate to the study, try to increase water demand and to take steps to ensure as much rain as possible reaches the catchment surface e.g. by managing any overhanging foliage. The cost of mains water is outside the control of the hotel owners and so little can be done about the effects of this particular parameter.

For Pay-Back Period

- Pay-back period only showed any sensitivity to changes in two parameters: daily water demand (0 years for best case, +2 years for worst case, 2 years total change) and mains water cost (0 years for best case, -1 years for worst case, 1 year total change)

- Conclusion: pay-back period results are relatively insensitive to changes and are unlikely to vary significantly from the expected scenario results. However, it may be possible to reduce the pay-back period slightly by increasing water demand above the expected level

For % Demand Met

- % demand met performance showed little sensitivity to changes in any of the variable parameters. Only two parameters showed any changes to the % demand met of over 1%: rainfall profile (0% for best case, -6.5% for worst case, 6.5% total change) and daily water demand (-2.9% for best case, 0% for worst case, 2.9% total change)
- Conclusion: % demand met results are insensitive to changes and are unlikely to vary significantly from the expected scenario results

Conclusions

The analysis has shown that a RWH system would be a feasible and cost-effective addition to the hotel. The main conclusions from the analysis are summarised below:

- Using a $6m^3$ storage tank, savings of £15,742 over 50 years can be expected (applying a discount rate of 3.5%) as compared to relying on mains-only water
- On a year-by-year basis, average savings of £315/yr can be expected (applying a discount rate of 3.5%) as compared to relying on mains-only water
- Expected pay-back period is 3 years and expected % of demand met for non-potable use is 100%.
- Scenario modelling showed that even under the worst likely conditions, long-term savings would still be observed (£3,671 over 50 years, discounted at 6.0% per year) and year-by-year savings would still also be observed (average of £73 per year, discounted at 6.0% per year)
- Sensitivity analysis showed that the proposed RWH system is generally insensitive to changes in most of the variable parameters.
- For those variable parameters that resulted in significant changes to the long-term savings during the sensitivity analysis (discount rate, water demand, mains water cost and rainfall profile) steps should be taken to ensure that a) the figures used in the analysis are as accurate and applicable to the system under study as possible, and b) that steps be taken to maximise the potential benefits offered by these variable parameters as highlighted by the sensitivity analysis.
- In conclusion, the modelled RWH system represents a good financial investment with a low inherent risk of long-term financial loss.

Appendix 5

Validating the Hydraulic Model

In order to ensure that RainCycle's predictions of future RWH system performance are realistic, the hydraulic components were validated against an existing methodology.

Model validation was conducted by comparing the hydraulic outputs of RainCycle against a methodology described by Fewkes & Warm in their 2001 conference paper *A Method of Modelling the Performance of Rainwater Collection Systems in the UK*. (Fewkes and Warm, 2001). This method involved modelling the daily performance of rainwater harvesting systems at eleven locations in the UK using a computer based behavioural model in conjunction with site-specific rainfall data. Performance curves (tank size vs. percentage of demand met) for each site were determined, and from these a set of generic curves created which can be used to predict the performance of RWH systems anywhere within the UK. These performance prediction curves "…*provide a valuable design aid for the accurate and therefore economic sizing of rainwater collection systems*."

Site-specific performance curves were generated by a computer program utilising Fewke's approach. Five parameters were used to create the curves: average annual rainfall for the catchment under study (mm/yr), catchment surface area (m^2), average daily demand (litres/day), catchment surface runoff coefficient and rainwater filter coefficient.

Both the RainCycle and Fewke's methods were used to model the RWH systems from the tutorial chapter and the three case studies from appendix 4. Recorded rainfall statistics were used with RainCycle in order to ensure maximum realism. These were selected from data sets recorded at the Emily Moor weather station located in Huddersfield, West Yorkshire. A year with a total rainfall depth of 886mm/yr was used since this is close to the yearly average for the Yorkshire region (885mm/yr).

The results from these comparisons are the focus of this appendix.

Validation 1: Tutorial Case Study

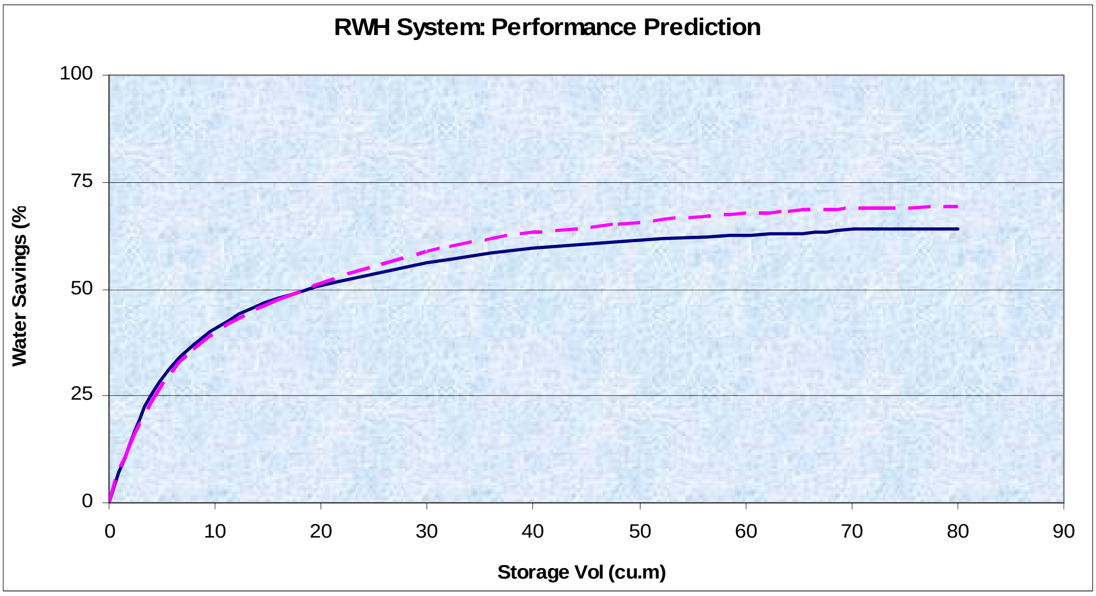
See chapter 3 for specific details about the tutorial RWH system. The parameter values used to generate the Fewkes performance curves for this case study are as follows:

Parameter	Value
Average annual rainfall (mm/yr)	886
Catchment surface area (m^2)	1,845m^2
Average daily water demand (litres/day)	4,236
Runoff coefficient	0.85
Filter coefficient	0.90

Comparison of Results

The following table and corresponding graph show the tank size vs. percentage of demand met predicted by both the Fewkes methodology and the RainCycle model.

Tank Size (m^3)	Fewkes: % Demand Met	RainCycle: % Demand Met	Difference (%)
0.000	0	0	0%
2.006	14	13	-5%
4.011	25	23	-7%
8.022	37	36	-3%
16.044	48	48	-1%
32.088	57	60	5%
48.132	61	65	6%
64.176	63	68	8%
72.198	64	69	7%
80.220	64	69	8%



Key: blue solid line = Fewkes methodology. Dashed purple line = RainCycle model

The results show that the predicted performance in terms of tank size vs. percentage of demand met is similar for both the Fewkes methodology and the corresponding RainCycle model. The RainCycle results are slightly more optimistic for larger tank sizes although all results are still within +/-8% of each other with an average difference of 2%.

Validation 2: Case Study 1 – Typical Domestic System

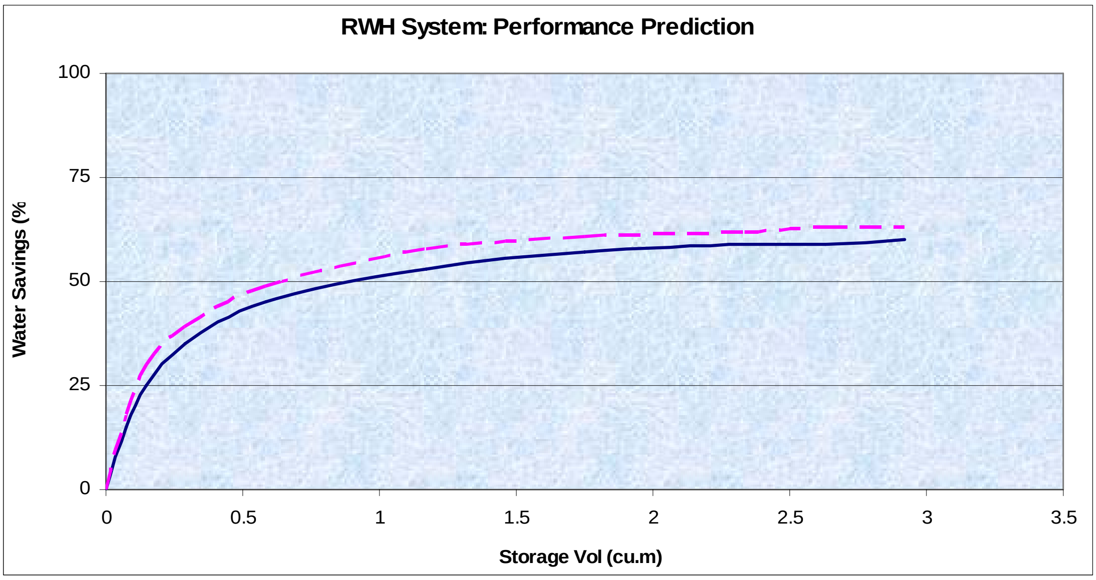
See appendix 4 for specific details about the case study 1 RWH system. The parameter values used to generate the Fewkes performance curves for this case study are as follows:

Parameter	Value
Average annual rainfall (mm/yr)	886
Catchment surface area (m^2)	50
Average daily water demand (litres/day)	146
Runoff coefficient	0.85
Filter coefficient	0.90

Comparison of Results

The following table and corresponding graph show the tank size vs. percentage of demand met predicted by both the Fewkes methodology and the RainCycle model.

Tank Size (m^3)	Fewkes: % Demand Met	RainCycle: % Demand Met	Difference (%)
0.000	0	0	0%
0.073	15	18	17%
0.146	25	30	17%
0.292	35	39	10%
0.584	45	49	8%
1.168	53	58	9%
1.752	57	61	7%
2.336	59	62	5%
2.628	59	63	6%
2.920	60	63	5%



Key: blue solid line = Fewkes methodology. Dashed purple line = RainCycle model

The RainCycle model predicted slightly more optimistic results than Fewkes. Predicted system performance is within +/-17% if all results are taken into account. Ignoring the outliers means that 8 out of 10 results are within +/-10%. The average difference is 8% (including the outliers).

Validation 3: Case Study 2 – Another Typical Domestic System

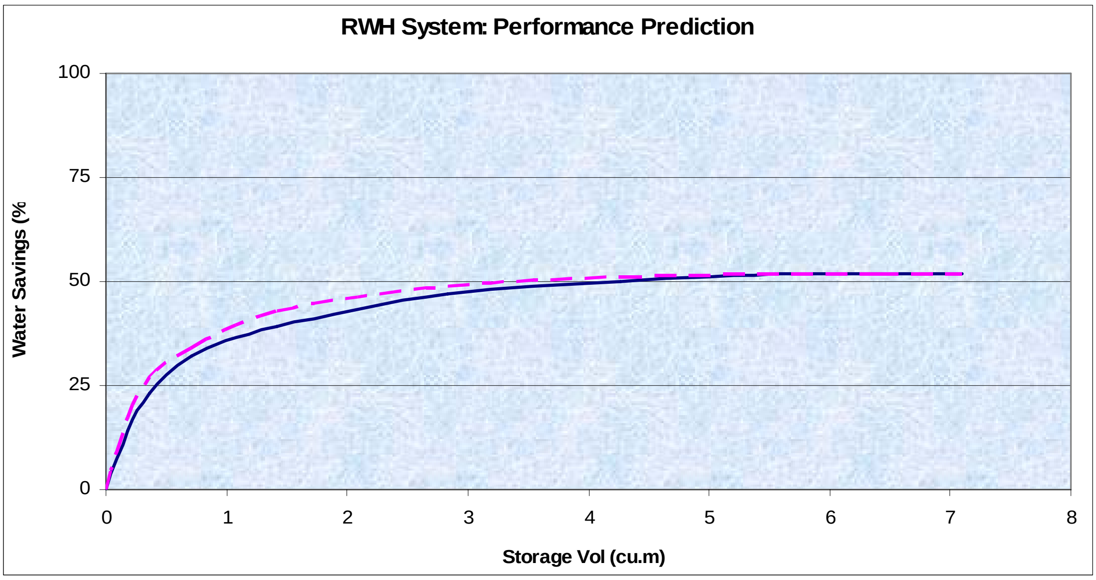
See appendix 4 for specific details about the case study 2 RWH system. The parameter values used to generate the Fewkes performance curves for this case study are as follows:

Parameter	Value
Average annual rainfall (mm/yr)	886
Catchment surface area (m^2)	100
Average daily water demand (litres/day)	355
Runoff coefficient	0.85
Filter coefficient	0.90

Comparison of Results

The following table and corresponding graph show the tank size vs. percentage of demand met predicted by both the Fewkes methodology and the RainCycle model.

Tank Size (m^3)	Fewkes: % Demand Met	RainCycle: % Demand Met	Difference (%)
0.000	0	0	0%
0.178	14	17	18%
0.355	23	27	15%
0.710	32	34	6%
1.420	39	43	9%
2.840	47	49	4%
4.260	50	51	2%
5.680	52	52	0%
6.390	52	52	0%
7.100	52	52	0%



Key: blue solid line = Fewkes methodology. Dashed purple line = RainCycle model

In this instance RainCycle gave slightly more optimistic results for the smaller tank sizes. For the larger tank sizes (700 litres and greater) the results are closely matched. All results are within +/-18%. Ignoring the outliers means that 8 out of 10 results are within +/-9%. The average difference is 5% (including the outliers).

Validation 4: Case Study 3 – Hotel System

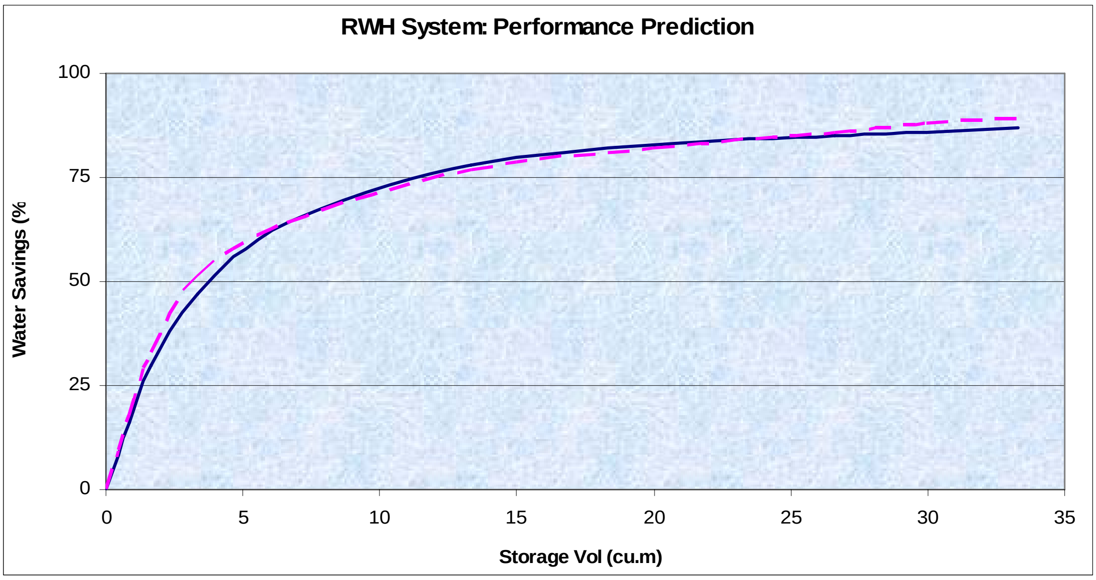
See appendix 4 for specific details about the case study 3 RWH system. The parameter values used to generate the Fewkes performance curves for this case study are as follows:

Parameter	Value
Average annual rainfall (mm/yr)	886
Catchment surface area (m^2)	2000
Average daily water demand (litres/day)	1664
Runoff coefficient	0.55
Filter coefficient	0.90

Comparison of Results

The following table and corresponding graph show the tank size vs. percentage of demand met predicted by both the Fewkes methodology and the RainCycle model.

Tank Size (m^3)	Fewkes: % Demand Met	RainCycle: % Demand Met	Difference (%)
0.000	0	0	0%
0.832	16	18	11%
1.664	30	33	9%
3.328	47	51	8%
6.656	64	64	0%
13.312	78	77	-1%
19.968	83	82	-1%
26.624	85	86	1%
29.952	86	88	2%
33.280	87	89	2%



Key: blue solid line = Fewkes methodology. Dashed purple line = RainCycle model

Again RainCycle gave slightly more optimistic results for the smaller tank sizes. For the larger tank sizes (660 litres and greater) the results are closely matched. All results are within +/-11%. Ignoring the outliers means that 7 out of 10 results are within +/-2%. The average difference is 3% (including the outliers).

Summary and Conclusions

The ability of RainCycle to accurately predict future RWH system performance was tested against an existing methodology (Fewkes & Warm, 2001). Both methods were used to test the performance of a number of RWH systems: 1 actual system and 3 theoretical (though realistic) systems.

The investigation showed that, for each system investigated, both methods gave similar results when predicting the percentage of demand met for a range of tank sizes. Ignoring the effects of any outliers, all results were within agreement by +/-10%, with an overall average difference of 5.5% (including any outliers).

In conclusion, the RainCycle method for predicting RWH system performance is in close agreement with the Fewkes methodology. Assuming that Fewkes gives accurate results then it can be stated with confidence that RainCycle also gives accurate results.

References

Fewkes & Warm (2001). *A Method of Modelling the Performance of Rainwater Collection Systems in the UK*. Proceedings from the First National Conference on Sustainable Drainage. 18^{th}-19^{th} June 2001. Coventry University.

Appendix 6

Bill of Quantities for a Typical RWH Storage Tank

The following information was obtained from a UK RWH system supplier (name withheld for reasons of confidentiality). The BoQ contains quantities but not costs since these are subject to change and are often site-specific. It is recommended that up-to-date and site-specific costs are calculated on a case-by-case basis e.g. by using the SPONS Civil Engineering and Highway Works Price Book or similar.

Standard Depth: 500mm to invert of storage tank

	Storage tank size (m^3)								
Item	**3.0**	**6.0**	**12.0**	**18.0**	**22.5**	**27.5**	**36.0**	**45.0**	**54.0**
Excavate not exceeding 4.5m deep and cart away from site	$11m^3$	$20m^3$	$36m^3$	$50m^3$	$59m^3$	$70m^3$	$86m^3$	$104m^3$	$122m^3$
Planking and strutting to sides of excavation n.e. 4.5m deep	$22m^2$	$31m^2$	$45m^2$	$52m^2$	$57m^2$	$64m^2$	$74m^2$	$85m^2$	$96m^2$
Level and ram bottom of excavation to receive concrete	$5m^2$	$8m^2$	$15m^2$	$16m^2$	$18m^2$	$22m^2$	$27m^2$	$32m^2$	$38m^2$
Concrete C30 in 150mm thick base	$5m^2$	$8m^2$							
Concrete C30 in 225mm thick base			$15m^2$	$16m^2$	$18m^2$	$22m^2$	$27m^2$	$32m^2$	$38m^2$
Fabric reinforcement (reference A142)			$15m^2$	$16m^2$	$18m^2$	$22m^2$	$27m^2$	$32m^2$	$38m^2$
Concrete C30 in 150mm thick surround hand compacted in 150mm layers	$4m^3$	$7m^3$							
Concrete C30 in 225mm thick surround hand compacted in 150mm layers			$17m^3$	$29m^3$	$32m^3$	$38m^3$	$45m^3$	$52m^3$	$60m^3$
Concrete C30 in 150mm thick surround to access shaft	$0.2m^3$	$0.2m^3$	$0.2m^3$	$0.2m^3$	$0.2m^3$	$0.2m^3$	$0.2m^3$	$0.2m^3$	$0.2m^3$
Formwork circular on plan to a radius of 450mm	$1.4m^2$	$1.4m^2$	$1.4m^2$	$1.4m^2$	$1.4m^2$	$1.4m^2$	$1.4m^2$	$1.4m^2$	$1.4m^2$

Quantities per additional 250mm depth to invert of storage tank

	Storage tank size (m^3)								
Item	**3.0**	**6.0**	**12.0**	**18.0**	**22.5**	**27.5**	**36.0**	**45.0**	**54.0**
Excavate not exceeding 4.5m deep and cart away from site	$1.3m^3$	$2.1m^3$	$3.2m^3$	$3.9m^3$	$4.5m^3$	$5.4m^3$	$6.7m^3$	$8.0m^3$	$9.5m^3$
Planking and strutting to sides of excavation n.e. 4.5m deep	$2.4m^2$	$3.3m^2$	$3.8m^2$	$4.0m^2$	$4.4m^2$	$5.0m^2$	$5.7m^2$	$6.6m^2$	$7.4m^2$
Concrete C30 in 150mm thick surround to access shaft	$0.2m^3$	$0.2m^3$	$0.2m^3$	$0.2m^3$	$0.2m^3$	$0.2m^3$	$0.2m^3$	$0.2m^3$	$0.2m^3$
Formwork circular on plan to a radius of 450mm	$1.4m^2$	$1.4m^2$	$1.4m^2$	$1.4m^2$	$1.4m^2$	$1.4m^2$	$1.4m^2$	$1.4m^2$	$1.4m^2$
Selected backfill material	$1.3m^3$	$2.1m^3$	$3.2m^3$	$3.9m^3$	$4.5m^3$	$5.4m^3$	$6.7m^3$	$8.1m^3$	$9.5m^3$