BACKGROUND TO THE SPORTS FIELD IRRIGATION SOFTWARE

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Executive Summary

This document provides a summary of the mathematics and logic used in the development of the Sportsfield Irrigation Software. The report is based around version 1.006 of the software. This version is the general release version of the software. There have been some changes from the initial v1.004 trial release. These changes are highlighted in Appendix A. While the mathematics is similar for most water sources, stormwater and decentralized water sources can vary significantly and the complexity of the models used in the software represents this.

The model is capable of calculating:

- The volume of water required for irrigation
- The volume of water supplied from various water sources after treatment
- The nutrient requirements for a turf
- The quality of water supplied from various water sources after treatment
- The cost offset from reducing fertilizer demand when using a nutrient rich water source
- The quantity of calcium that may be required to avoid sodicity issues
- The capital and operational costs of water treatment
- The greenhouse gas generation as a CO_2 equivalent of water treatment
- Optimized storage volume for a specified volumetric reliability
- Optimized decentralized catchment sizes for a specified volumetric reliability

The software itself has been programmed using Visual Basic .NET and utilizes the 2007 version of Excel. As a result, the software requires as a minimum access to Microsoft Office 2007 or 2010.

Glossary of Symbols

A_{catch}	Area of stormwater catchment
$A_{exposed}$	Area of stormwater storage that is exposed to potential of evaporation
A_{field}	Area of sports field or turf to be irrigated
A_{roof}	Area of roof used for rainwater harvesting
$c_{Ca_{req}}$	The additional concentration of calcium required to ensure soil protection for an irrigation water
c_x	The average concentration of species x in a water source
$c_{x_{base}}$	The average concentration of species x in stormwater baseflow
$c_{x_{bush}}$	The average concentration of species x in the runoff from bushland and forest
$c_{x_{handwash}}$	The average concentration of species x in water from a basin
$c_{x_{irr}}$	The average concentration of species x in irrigation water
$c_{x_{kitchen}}$	The average concentration of species x in wastewater collected from a kitchen
$c_{x_{lawn}}$	The average concentration of species x in runoff from lawn and garden areas
$c_{x_{pave}}$	The average concentration of species x in runoff from paved areas
$c_{x_{road}}$	The average concentration of species x in runoff from roads
$c_{x_{roof}}$	The average concentration of species x in runoff from roofs
$c_{x_{shower}}$	The average concentration of species x in wastewater from a shower
$c_{x_{toilet}}$	The average concentration of species x in wastewater from a toilet
d_{ET_n}	The evapotranspiration from a turf surface on day n in mm
d_{evap_n}	The evaporation on day n in mm
d_{irr_n}	The irrigation depth required on day n in mm
d_{rain_n}	The rainfall on day n in mm
d_{rz}	The rootzone depth
d_{SM_n}	Depth equivalent for soil moisture in the rootzone on day n
d_{SMC}	Depth equivalent for soil moisture capacity in the rootzone

$d_{SMC_{bush}}$	Depth equivalent for soil moisture capacity in the rootzone of bushland in a stormwater catchment
$d_{SMC_{lawn}}$	Depth equivalent for soil moisture capacity in the rootzone of lawns/gardens in a stormwater catchment
$f_{greytreat}$	Fraction of greywater remaining after treatment
$f_{sewerinflow}$	Fraction of stormwater lost to sewer inflows
$f_{stormtreat}$	Fraction of stormwater remaining after treatment
$f_{x_{stormtreat}}$	Fraction of species *x* remaining in stormwater after treatment
$k_{baseflow}$	Base flow recession constant, the fraction of groundwater that infiltrates into the stormwater collection system
k_{BFI}	Base flow index, the fraction of excess water (i.e. water in excess to soil saturation) on pervious surfaces that permeates through to a groundwater aquifer
k_c	Crop factor for calculating evapotranspiration from pan evaporation data. It is ultimately the fraction of evaporation and transpiration from a turfed surface compared to evaporation from the flat surface of water.
$k_{c_{bush}}$	Crop factor for calculating evapotranspiration from bushland in a stormwater catchment
$k_{c_{lawn}}$	Crop factor for calculating evapotranspiration from lawns and gardens in a stormwater catchment
k_{II}	Groundwater infiltration index, the fraction of excess water (i.e. water in excess to soil saturation) that is lost to infiltration into the sewer network
k_{SWR}	Soil water retention factor in mm.cm^{-1}
m_{x_n}	The total mass of component *x* in the stormwater storage on day *n*
n_{houses}	The number of houses in a decentralized catchment
$n_{houses_{new}}$	The number of houses in a decentralized catchment for the next iteration in a catchment size optimization
$n_{occupancy}$	The average occupancy of houses in a decentralized catchment
$n_{showerusers}$	The weekly average of shower users in a local grey/recycled water catchment
$n_{visitors}$	The weekly average number of visitors to the sportsfield at the centre of a local grey/recycled water catchment
$Q_{baseflow_n}$	The daily flow of water into a stormwater treatment system as a baseflow on day *n*

$Q_{bushrun_n}$	The daily flow of runoff from bushland on day *n*
$Q_{lawnrun_n}$	The daily flow of runoff from lawns and gardens on day *n*
Q_{max}	Maximum daily flow of water to a treatment system
$Q_{paverun_n}$	The daily flow of runoff from paved areas on day *n*
$Q_{roadrun_n}$	The daily flow of runoff from roads on day *n*
$Q_{roofrun_n}$	The daily flow of runoff from roofs on day *n*
$Q_{stormtreat_n}$	The daily flow of water into a stormwater treatment system on day *n*
SAR	Sodium adsorption ratio of an irrigation water
$V_{aquifer_n}$	Volume of water stored in a groundwater aquifer on day *n*
$V_{bush_{evap}}$	The volume of water lost through evapotranspiration from bushland areas in a stormwater catchment
$V_{bush_{impervrun}}$	The volume of water that runs onto bushland areas as runoff from impervious surfaces
$V_{bush_{rain}}$	The volume of rain falling on bushland areas in a stormwater catchment
$V_{bushexcess_n}$	The volume of water falling on bushland in a stormwater catchment in excess of that needed to saturate the soil on day *n*
$V_{bushstore_n}$	The volume of water stored in soil in bushland areas of a stormwater catchment on day *n*
$V_{grey_{max}}$	The maximum volume of greywater available annually
V_{grey_n}	The volume of recycled greywater used on day *n*
$V_{grey_{total}}$	The total volume of recycled greywater used in one year
$V_{greyhouse}$	The volume of raw greywater produced per house in a decentralized greywater catchment
$V_{greystored_n}$	The volume of treated greywater in storage on day *n*
$V_{greytank}$	The volume of greywater tank/storage
$V_{handwash}$	The average volume of water used in a single handwash
V_{irr_n}	The volume of irrigation water required on day *n*
$V_{kitchen}$	The weekly average of water used in a canteen/kitchen at a sports field

$V_{lawn_{evap}}$	The volume of water lost through evapotranspiration from lawn/garden surfaces in a stormwater catchment
$V_{lawn_{impervrun}}$	The volume of water that runs onto lawn/garden surface as runoff from impervious surfaces
$V_{lawn_{rain}}$	The volume of rain falling on lawn/garden surfaces in a stormwater catchment
$V_{lawnexcess_n}$	The volume of water falling on lawns and garden surfaces in a stormwater catchment in excess of that needed to saturate the soil on day *n*
$V_{lawnstore_n}$	The volume of water stored in soil in a lawn/garden area of a stomwater catchment on day *n*
V_{person}	The average water use in a decentralized catchment per person per day
$V_{potable_n}$	The volume of potable water used on day *n*
V_{rain_n}	The volume of rainwater used on day *n*
$V_{rainstored_n}$	The volume of rainwater in storage on day *n*
$V_{raintank}$	The volume of a rainwater tank
$V_{raintank_{new}}$	The volume of the rainwater tank used in the next iteration of optimization calculations
V_{shower}	The average volume of water used per shower in a local shower block
V_{storm_n}	The volume of stormwater used on day *n*
$V_{stormover_n}$	The volume of stormwater that overflows from storage on day *n*
$V_{stormstored_n}$	The volume of stormwater in storage on day *n*
$V_{stormtank}$	The volume of the stormwater storage
ε_{irr}	Irrigation efficiency
ρ	Volumetric reliability
ρ_{aim}	Targeted volumetric reliability
ρ_{new}	The volumetric reliability achieved during the next iteration of optimization calculations
$\%_{bush}$	The fraction of a catchment occupied by bushland
$\%_{greyshandy}$	The fraction of greywater in shandied irrigation water
$\%_{lawn}$	The fraction of a catchment occupied by lawns/gardens

$\%_{pavement}$	The fraction of a catchment occupied by pavement
$\%_{paveconn}$	The fraction of pavement that is connected to a stormwater collection system (i.e. does not runoff to pervious surfaces)
$\%_{road}$	The fraction of a catchment occupied by roads
$\%_{roadconn}$	The fraction of road that is connected to a stormwater collection system (i.e. does not runoff to pervious surfaces)
$\%_{roof}$	The fraction of a catchment occupied by roofs
$\%_{roofconn}$	The fraction of roofs that is connected to a stormwater collection system (i.e. does not runoff to pervious surfaces)

Table of Contents

1. Introduction

The following report outlines the data and modelling used as part of the Sports Field Irrigation Software developed for the Smart Water Fund project Sustainable Water Options for Sportsfields. The report has been compiled based around version 1.006 of the software developed in June 2011. This represents the release version of the software. The first external version of this software was version 1.004 that was released to water authorities and version 1.005 that was used as part of a trial with local council authorities. A comprehensive list of changes in versions 1.005 and 1.006 can be found in Appendix A.

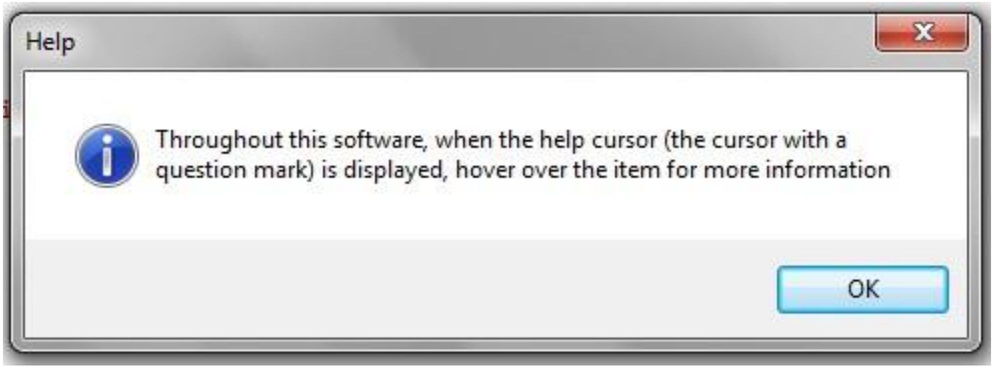
The report is split into three sections. Section 2 will deal with the input screens. Here will be explained what details the users is required to input and what form they should take. It also explains where different systems values were taken or adapted from. Section 3 discusses the calculations behind the model in the software, where they came from and what data sources have been used. Section 4 discusses the outputs from the simulation.

2. Overview of the Programme – Inputs

The program was developed in Visual Basic .NET using the Microsoft software Visual Studio 2008 and updated later using Visual Studio 2010. It was designed primarily to collect data from the user and to interface with Microsoft Excel for the outputs of the programme. Due to the changes in Microsoft Office products this means the software will work only with Office 2007 or 2010 installed. The following is a window-by-window description of the software including screen grabs of all windows used. The screen grabs were made from the programme running in a Windows 7 environment. The appearance of the software may change in other versions of Windows.

2.1 Opening Window

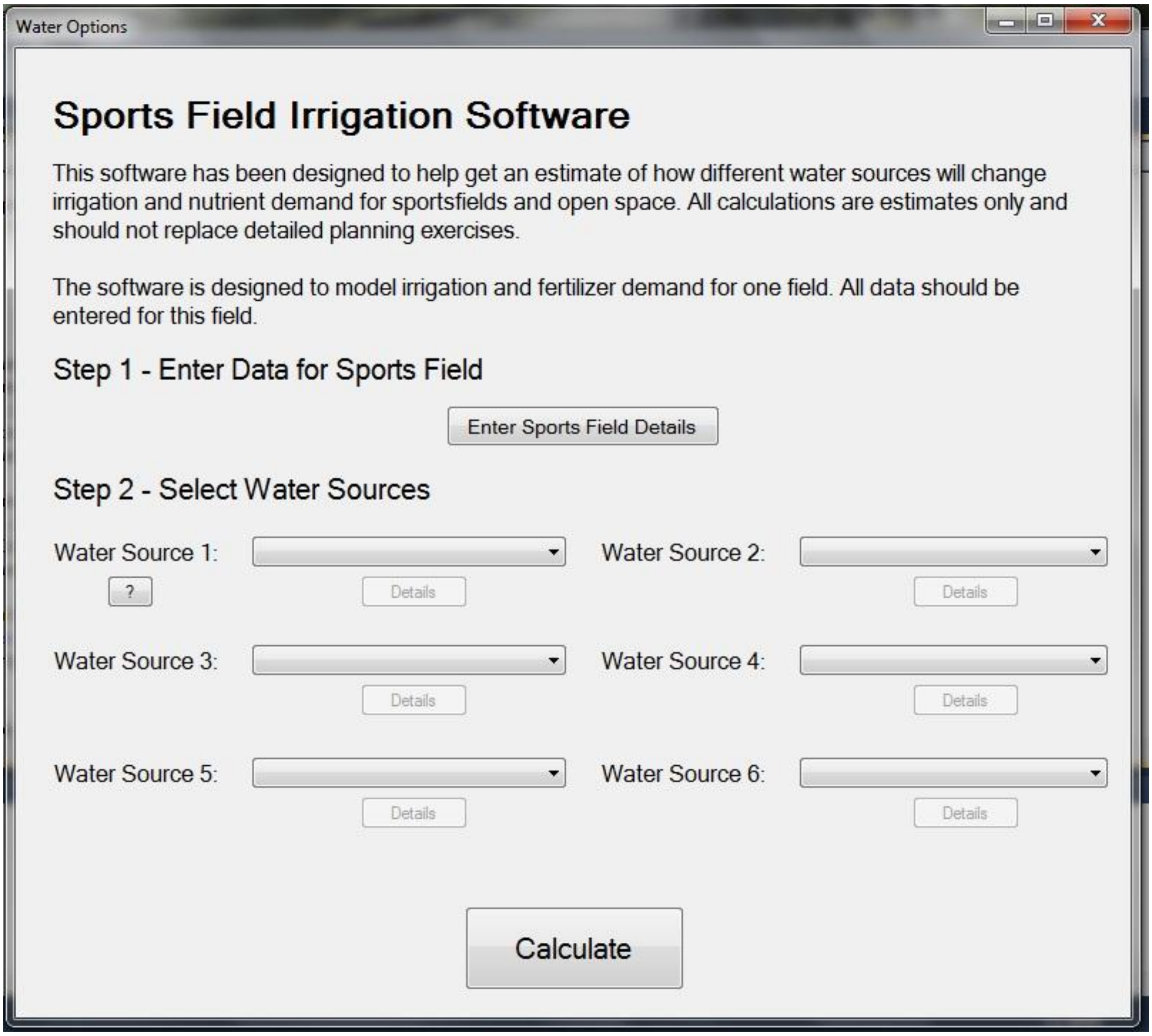
The program starts with the message window shown in Figure 1. This is a general message informing the user that “Throughout this software, when the help cursor (the cursor with a question mark) is displayed, hover over the item for more information.” After clicking “OK” the programme then proceeds to the main window.



Throughout this software, when the help cursor (the cursor with a question mark) is displayed, hover over the item for more information

Figure 1: The initial message window displayed upon starting the programme. This is to alert the user to the use of tooltips through the software.

Figure 2 shows the opening window of the software. In an improvement on previous versions it more clearly guides the user through the processes they must follow for the software to work. Here it is highlighted that the software is designed only for provided estimates and should not replace details planning exercises. It also notes that the software is designed to consider one field at a time and should be used accordingly. To perform Step 1 in providing data for the sports field, the user must click the button labelled “Enter Sports Field Details.” This will open the Sportsground Details Window described in Section 2.2.



Sports Field Irrigation Software

This software has been designed to help get an estimate of how different water sources will change irrigation and nutrient demand for sportsfields and open space. All calculations are estimates only and should not replace detailed planning exercises.

The software is designed to model irrigation and fertilizer demand for one field. All data should be entered for this field.

Step 1 - Enter Data for Sports Field

Step 2 - Select Water Sources

Figure 2: The main window in the software. All of the programme’s sub-windows may be accessed from this page. Simulations are also run from here.

In Step 2, the user is expected to provide information on the water to be used in the simulation. This is done through the dropdown menus. Ultimately a total of six water sources may be used in one simulation. The dropdown contains the following possible choices:

- None (this is for use when the user wishes to cancel the use of a water source)
- Rainwater
- Stormwater
- Recycled Grey Water
- Centralized Recycled Water (this is the option for Class A/B/C water from a centralized location such as Eastern Treatment Plant or Western Treatment Plant in Melbourne. The inputs for this option are treated sewage parameters).
- Decentralized Recycled Water (this is the option for sewer mining or the establishment of new decentralized sewage treatment systems. The inputs for this option are raw sewage parameters)
- Ground Water
- Brackish Water
- Sea Water
- Custom Water (this is an option for any water source that quality parameters are known for. The software does not support estimates or treatment for this water sources)

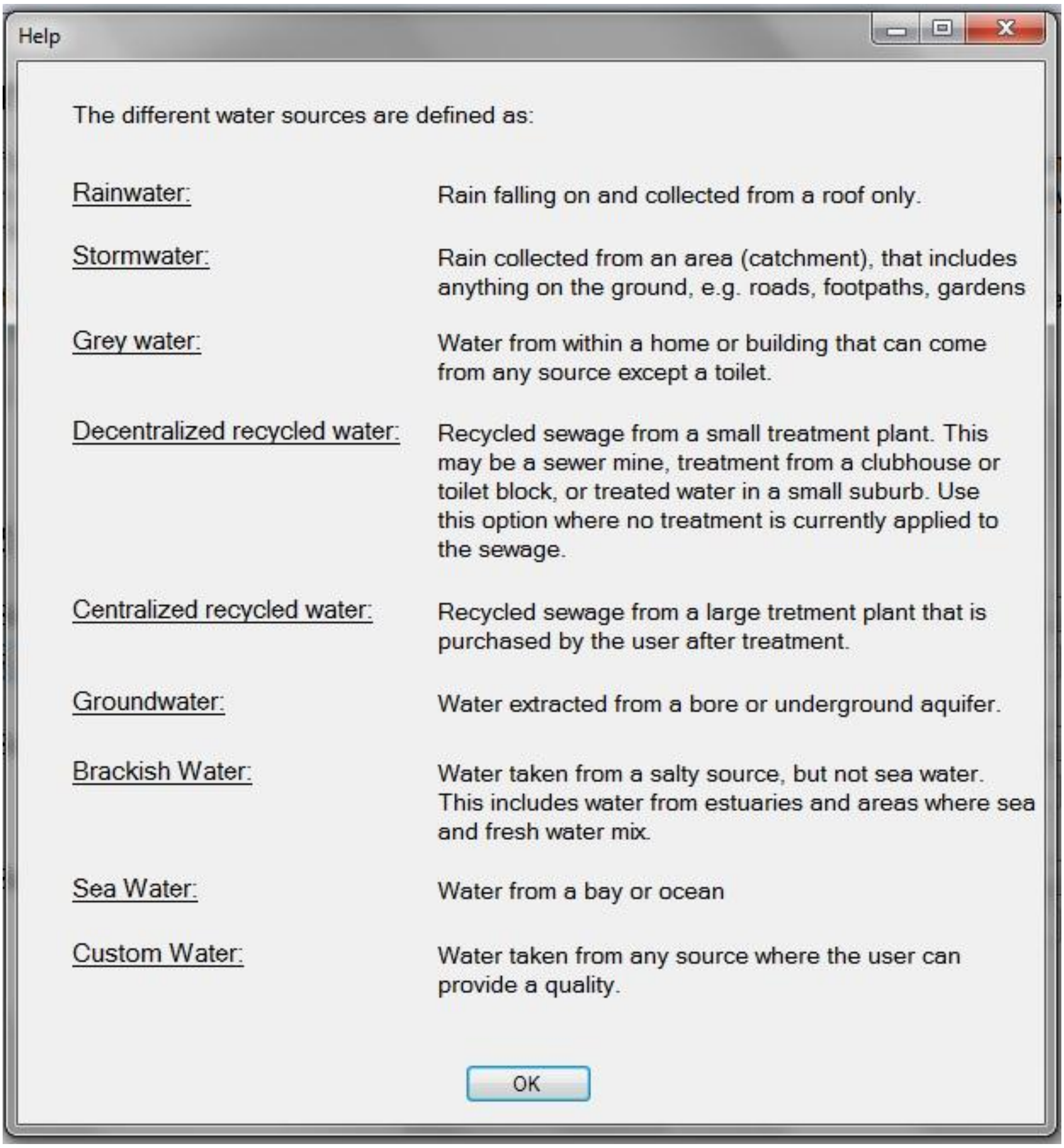
To assist users in definitions tooltips are used to guide users to the "?" button that will open a help window with the definitions of the water sources. This window is shown in Figure 3. Once a selection has been made the "Details" button will be made available. Clicking this button will open a new window where users can enter details about the water source. These windows are discussed in Sections 2.3 to 2.12.

The "Calculate" button will run the simulation, but only if the sportsground and water source details have been entered. Clicking this button will perform the calculations described in Section 3 and display the results in Excel as described in Section 4. The programme remains open during this time and further simulations may be run.

2.2 Sportsground Details

Figure 4 shows the Sportsground Details window that opens when the menu item "Sportsground Details" is clicked on the front page of the software. The information collected here is used to determine irrigation and fertilizer demand for a site during the simulation.

The "Turf Type" dropdown consists of three options: "Warm-season turf", "Cool-season turf" and "Comparison". While different turf species were considered, there was ultimately little difference between the main warm-season turf types [1] and therefore a simplified version was used. Selecting comparison allows the users to perform a comparison between warm- and cool-season turfs for the same field, however *only potable water will be used in the simulation*. No other water sources may be selected. When "Comparison" is chosen from this menu a message box displaying this warning will appear to remind the user of this condition.



The different water sources are defined as:

Rainwater:	Rain falling on and collected from a roof only.
Stormwater:	Rain collected from an area (catchment), that includes anything on the ground, e.g. roads, footpaths, gardens
Grey water:	Water from within a home or building that can come from any source except a toilet.
Decentralized recycled water:	Recycled sewage from a small treatment plant. This may be a sewer mine, treatment from a clubhouse or toilet block, or treated water in a small suburb. Use this option where no treatment is currently applied to the sewage.
Centralized recycled water:	Recycled sewage from a large tretment plant that is purchased by the user after treatment.
Groundwater:	Water extracted from a bore or underground aquifer.
Brackish Water:	Water taken from a salty source, but not sea water. This includes water from estuaries and areas where sea and fresh water mix.
Sea Water:	Water from a bay or ocean
Custom Water:	Water taken from any source where the user can provide a quality.

Figure 3: The Help Window for definitions of water type.

The “Soil Type” dropdown consists of six options based around the definitions of soil texture. This soil type is used to determine the water retention capacity of the soil and should be the *soil of the root zone only*. The supported soil types are:

- Sand
- Loamy sand
- Sandy Loam
- Loam
- Poor-structured Clay
- Good-Structured Clay

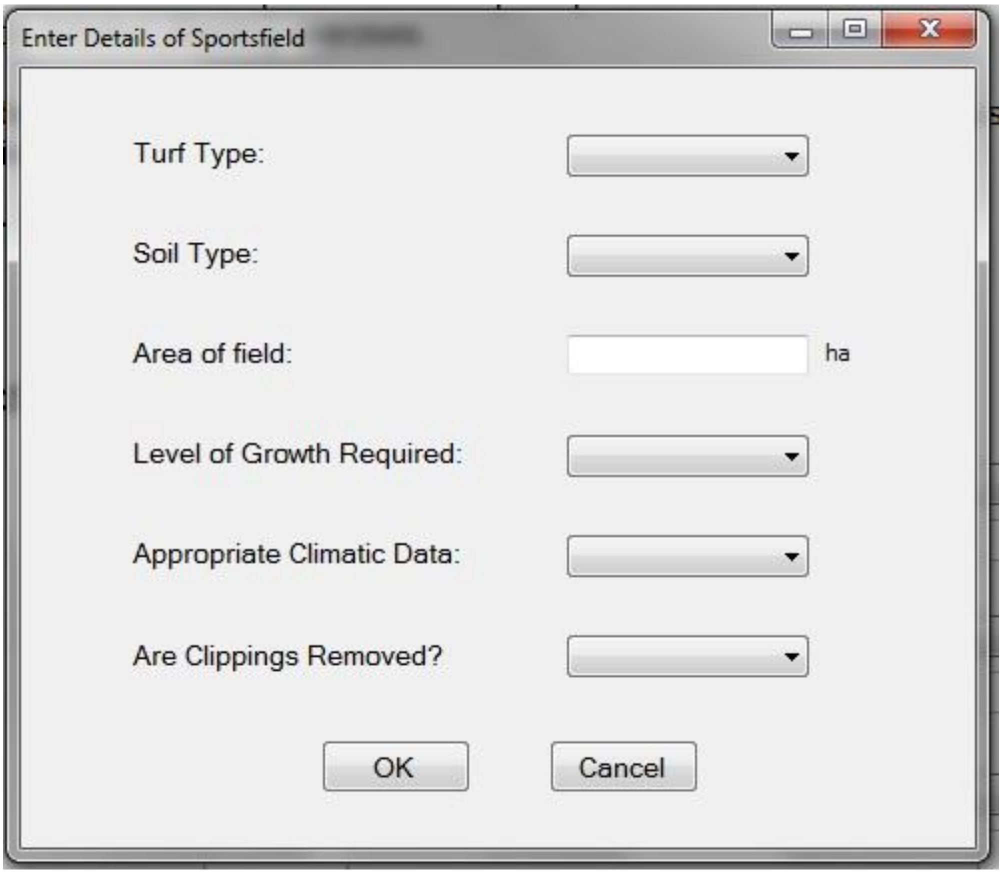


Figure 4: The Sportsground Details Window

Users are referred to the Australian Soil Texture Classification Triangle, information on which can be found through the Victorian Department of Primary Industries ([2] for example), for information on determining the soil texture type.

The “Area of Field” textbox should contain the area of the field and should be a number only (i.e. no text). This number should be given in hectares.

The “Level of Field” dropdown refers to the relative level of competition or importance of the field. The original five choices from this box have been reduced to three. They are defined by the amount of growth required and therefore influence the water irrigation requirements for the field. The three choices are:

- Strong growth. This would be a field that see a high level of use and has a high priority
- Average growth. This would be a field that sees a moderate to high level of use, but is not a high priority
- Just Acceptable growth. This would be a field that needs needs to just survive. This may be a training surface, turf for passive recreation or a minor competition field.

The “Appropriate Climatic Data” dropdown is for the selection of rainfall and evaporation statistics that are inbuilt to the programme. There are a number of options from the Greater Melbourne Region here:

- Beaumaris
- Bundoora
- Caulfield
- Cerberus
- Cheltenham
- Cranbourne
- Croydon
- Dromana
- Eltham
- Epping
- Flemington
- Glen Waverley
- Hawthorn
- Kangaroo Ground
- Keilor
- Laverton
- Lilydale
- Melbourne Airport
- Melbourne CBD
- Melton
- Mitcham
- Moorabbin
- Moorooduc
- Noble Park
- Oakleigh
- Preston
- Ringwood North
- Scoresby
- South Yarra
- Viewbank

It should be noted that each of these represents a weather station from the Bureau of Meteorology and contains rainfall data. Only three sites have individual evaporation data: Melbourne Airport, Melbourne CBD and Bundoora. Information on how the data was compiled is found in Section 3.1.

The “Are Clippings Removed?” dropdown has only two options: “yes” or “no”. This is used to ascertain how much nutrients are returned to the turf after mowing.

Clicking the “OK” button will save the inputs to memory only if the dropdown menus and the textbox have been given a value. Clicking the “Cancel” button will close the window without saving.

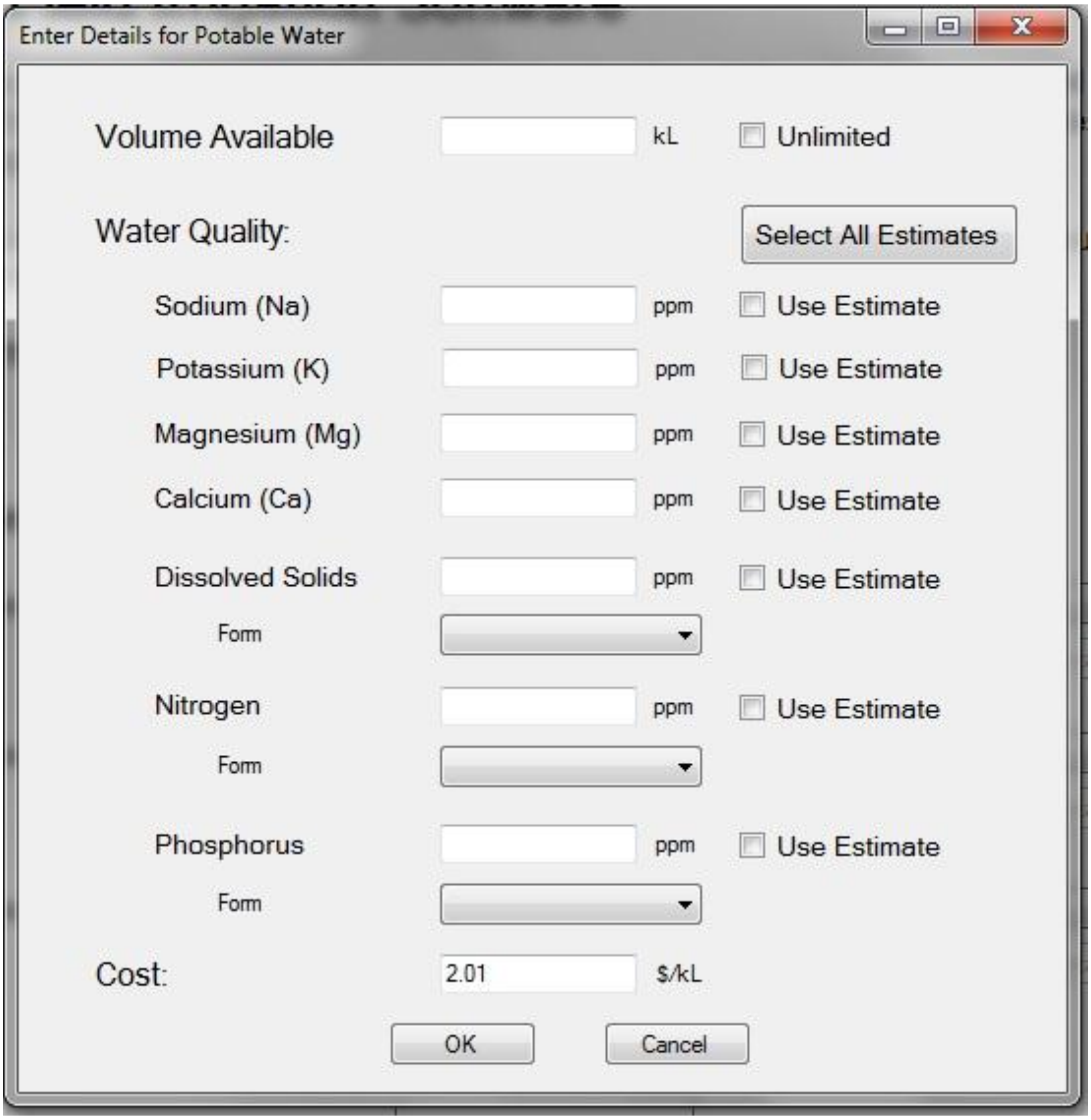
2.3 Potable Water Window

The Potable Water Window (shown in Figure 5) opens when the user selects potable water as a water source and clicks the “Details” button. At this window users are required to enter the volume and quality of water available.

The volume should be entered in kL.year^{-1}. Where water use is unlimited users can tick the “Unlimited” check box.

The water qualities should be entered in ppm. The exception to this is dissolved solids that may be entered in mS.cm^{-1} where “conductivity” is selected from the form dropdown.

Dissolved Solids, Nitrogen and Phosphorus have multiple forms they may be entered in to the software in. For Dissolved Solids this is “TDS” and “conductivity”. For Nitrogen this is “Total Nitrogen” and “Nitrates” and for Phosphorus this is “Total Phosphorus” and “Phosphates”



Cost: 2.01 $/kL

Figure 5: The Potable Water Window

Table 1: Estimates for potable water. Values derived from [3, 4]

Parameter	Estimate	Form
Sodium	7.3	
Potassium	1.35	
Magnesium	1.85	
Calcium	9	
Dissolved Solids	71	Total Dissolved Solids
Nitrogen	0.815	Nitrate
Phosphorus	0.007	Total Phosphorus

Selected the "Use Estimate" checkbox will take an estimated value for that parameter. For potable water this is the average water qualities for Melbourne, shown in Table 1. These values have been derived from the annual reports of the City West Water and South East Water [3, 4]. This has been updated using the 2010 data in version 1.006 of the software.

Finally, the Cost box allows users to enter a price for water in $\$.kL^{-1}$. A default value is pre-entered into this page at $\$2.01.kL^{-1}$ and is an average of the non-residential usage tariffs charged by Melbourne's three water retailers (City West Water, Yarra Valley Water and South East Water) as of 1 July 2011.

2.4 Rain Water Window

The Rain Water Window (shown in Figure 6) opens when rainwater is selected as a water source and the "Details" button in clicked. At this window users should enter information about the known qualities of the water and the size and location of the catchment in order to identify the volumes of water that are likely to be available.

At the "Select Location" dropdown, users select a location based on the weather stations from the Bureau of Meteorology. This is the same list shown in Section 2.2, however users do not have to select the same location. This location is used to determine rainfall.

The value entered into the "Catchment (Roof) Size" textbox is the size of the roof used to collect water in square metres. It must take the form of a number.

Table 2: Estimates for rain water. Adapted from [5-7]

Parameter	Estimate	Form
Sodium	43.4	
Potassium	10.1	
Magnesium	7.32	
Calcium	5.65	
Dissolved Solids	65	Total Dissolved Solids
Nitrogen	5.62	Total Nitrogen
Phosphorus	0.21	Total Phosphorus

The value entered into the “Tank Volume” textbox is the volume of the tank used to store water in kL. It must take the form of a number. The “optimize” check box may be selected to optimize the size of this tank based around demand and incoming volume. Checking this box will reveal a new parameter “Reliability.” This is the volumetric reliability and is equivalent to:

$$\rho_V = \frac{V_{supplied}}{V_{demand}} \qquad \textbf{Eqn 1}$$

Where ρ_V is the volumetric reliability, $V_{supplied}$ is the volume of rain water supplied and V_{demand} in the volume of water needed to meet the irrigation demand. The reliability is limited to being an integer between 1 and 100 (in percent).

The quality parameters are collected in the same way as potable water (see Section 2.3). The estimates are shown in Table 2 and have been derived from the scientific literature [57]. Measurements are converted between dissolved solids (in ppm) and conductivity (in $\mathrm{mS.cm^{-1}}$) using the equation:

$$c_{EC} = \frac{c_{TDS} \times 1.5}{1000} \qquad \textbf{Eqn 2}$$

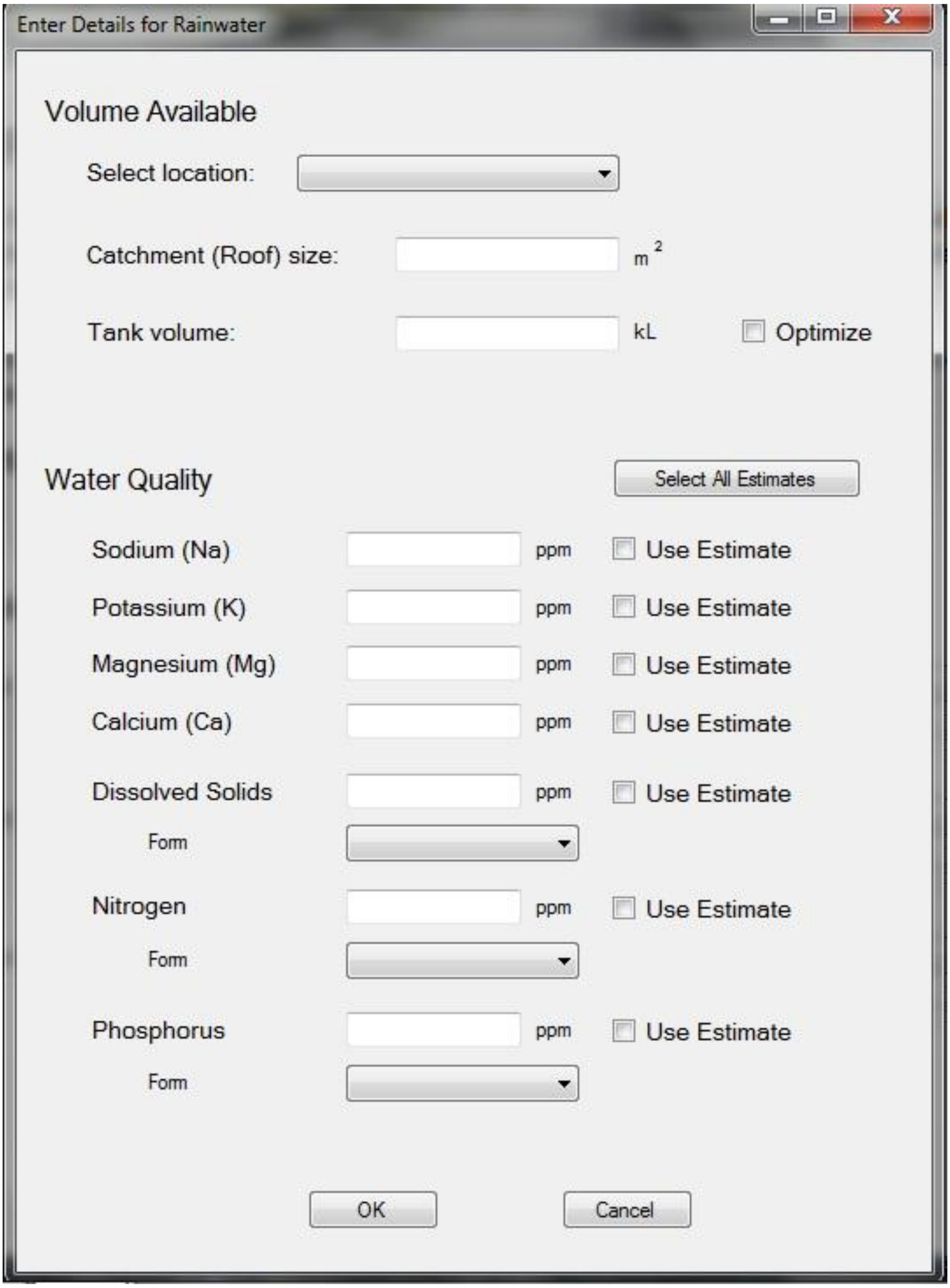


Figure 6. The Rain Water Window

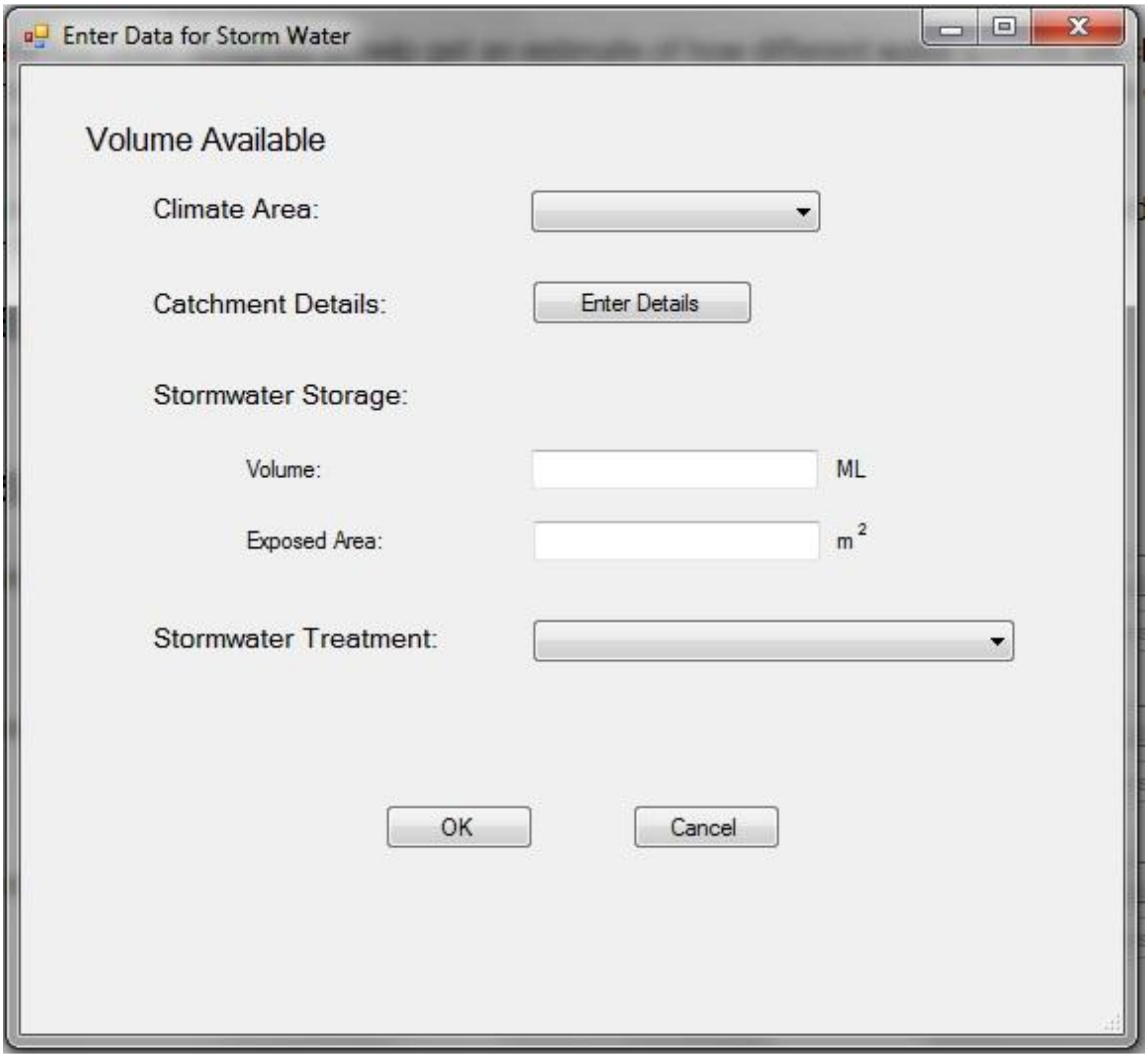


Figure 7: The Stormwater Window

2.5 Storm Water Windows

The Storm Water Window (Figure 7) opens when storm water is selected as a water source and the “details” button is clicked. This window accounts for the basic data needed for storm water reuse.

The “Climate Area” dropdown is a location based on the Bureau of Meteorology’s weather stations. The list can be found in Section 2.2. It is important to note that due to the size of some catchments the location of the field may not be the most accurate representation of location of the storm water catchment and therefore the location selected does not need to be the same. This data is used both for the volume of rain that falls within the catchment as well as the evaporation from pervious surfaces and evaporation from any open water storage that may be used.

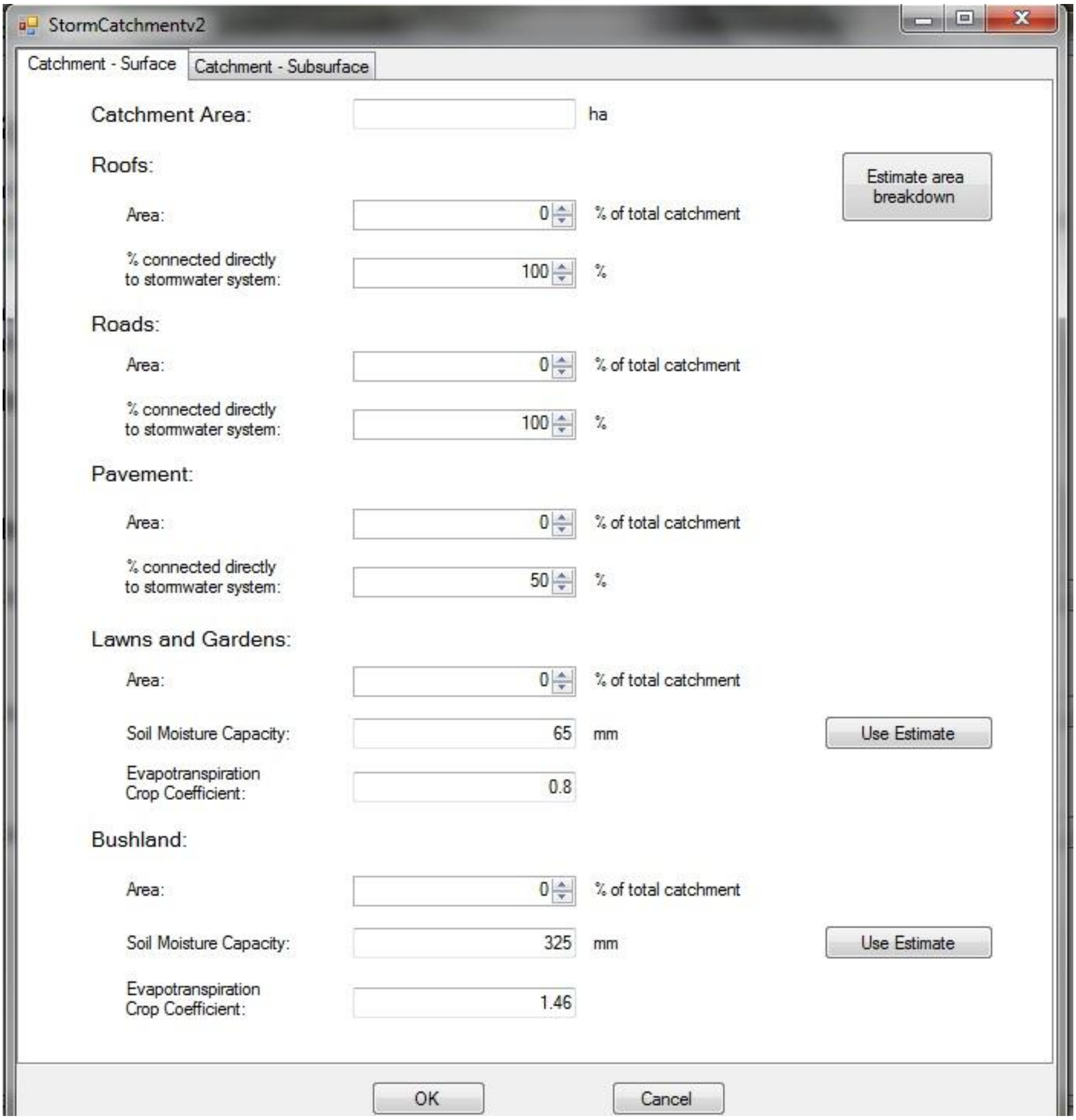
The volume of the stormwater storage ($V_{stormtank}$) is given in ML (N.B. this is different to the storage for all other water sources). Anything entered into this textbox must take the form of a number. The exposed area ($A_{exposed}$) is given in square metres and must also take the form of a number.

Stormwater treatment may be defined in the dropdown and can take three forms:

- None
- Wetlands
- Rain Garden

The treatment selected will help to define final water qualities, greenhouse gas emissions and costs for the reuse system.

Clicking the "Enter Details" button next to the label "Catchment Details" will open the Storm Water Catchment Window. This is shown in Figure 8 and Figure 9.



Catchment Area: ha

Roofs:
Area: 0 % of total catchment
% connected directly to stormwater system: 100 %

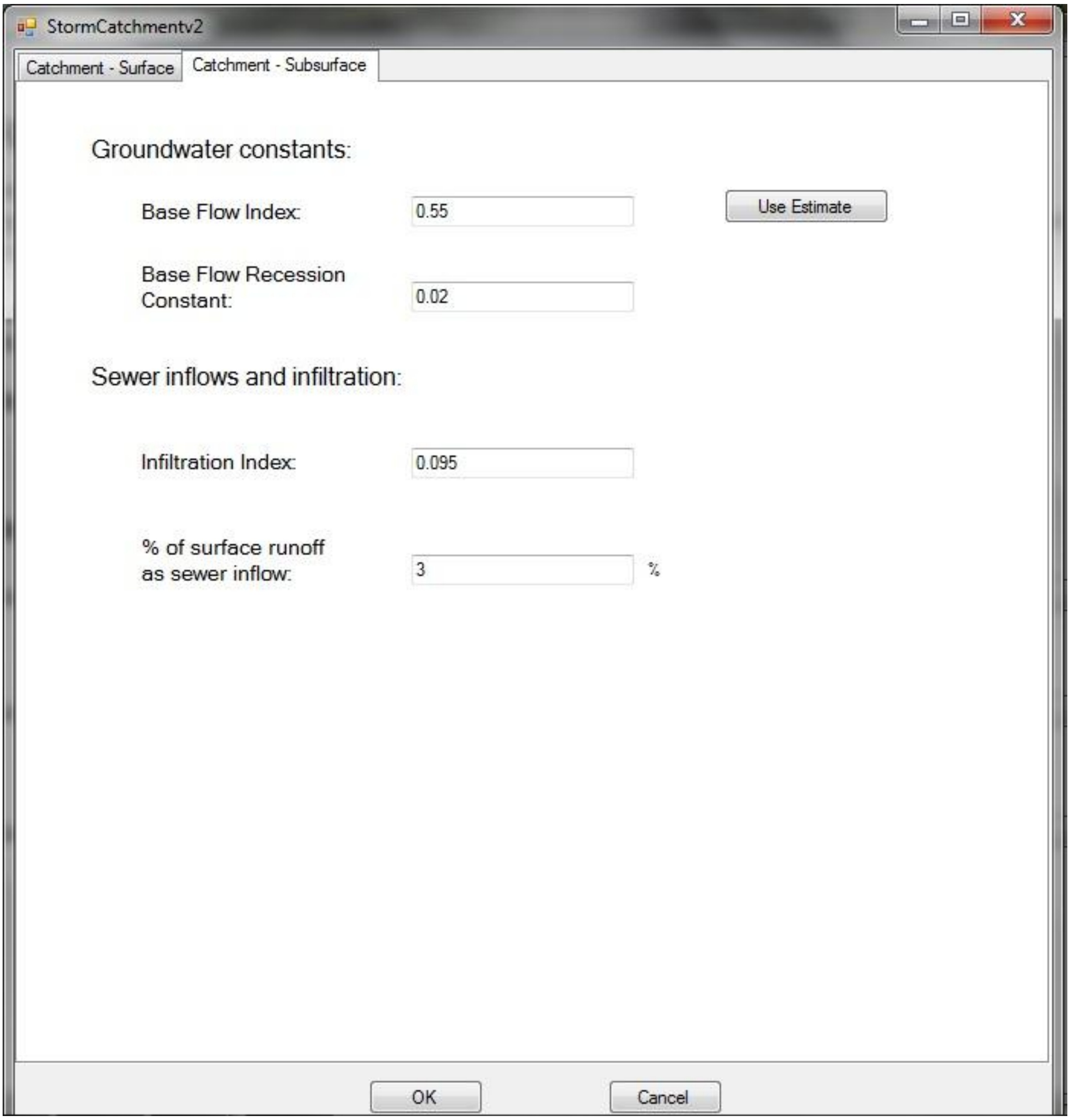
Roads:
Area: 0 % of total catchment
% connected directly to stormwater system: 100 %

Pavement:
Area: 0 % of total catchment
% connected directly to stormwater system: 50 %

Lawns and Gardens:
Area: 0 % of total catchment
Soil Moisture Capacity: 65 mm
Evapotranspiration Crop Coefficient: 0.8

Bushland:
Area: 0 % of total catchment
Soil Moisture Capacity: 325 mm
Evapotranspiration Crop Coefficient: 1.46

Figure 8: The Surface Tab of the Stormwater Catchment Window



Groundwater constants:

Base Flow Index: 0.55

Base Flow Recession Constant: 0.02

Sewer inflows and infiltration:

Infiltration Index: 0.095

% of surface runoff as sewer inflow: 3 %

Figure 9: The Subsurface Tab of the Stormwater Catchment Window

The data entered into the Storm Water Catchment Window will define the water volumes and quantities. It is split into two tabs, Surface and Subsurface. The Surface tab (shown in Figure 8) defines the surface properties of the catchment and ultimately derives most of the quality parameters and the wet weather flows. This information should generally be known to the user. The Subsurface tab (shown in Figure 9) ultimately defines the base flow or dry weather flow into the stormwater system. This is often information unknown to the user and comes prefilled with estimates. While this tab does not have to be viewed by the user, a warning will appear when the user clicks the "OK" button if they have not clicked on the Subsurface Tab.

On the surface tab, the catchment area (A_{catch}) is the area of the stormwater catchment. It should be a number given in hectares. The catchment area is then defined in a split between roof ($\%_{roof}$), pavement ($\%_{pave}$), roads ($\%_{road}$), gardens/open space ($\%_{lawn}$) and bushland/forest ($\%_{bush}$). These are given in percentages under their respective headings. The area of roof is defined only as the rain that can fall on a roof (residential, industrial or commercial). The software will not distinguish between roof types. The area of pavement is defined as driveways, courtyards, footpaths, asphalt/concrete playgrounds etc. Again the software will not distinguish between the various pavement materials. Roads are defined as any road (regardless of material). Gardens and open space are defined as any area that is pervious to water and does not contain a significant number of trees, while forest are the pervious areas that do contain significant numbers of trees. The sum of the percentage for each of these areas must equal 100. The "Estimate Area Breakdown" button can help make an estimate for these values. Clicking this button opens the Area Estimation Window, shown in Figure 10. Here the user selects a catchment type from the following categories:

- Central Business District
- Semidetached Housing (Inner City Suburb)
- Detached Housing (Outer Suburb)
- Industrial

This then distributes the area of the catchment according to Table 3.

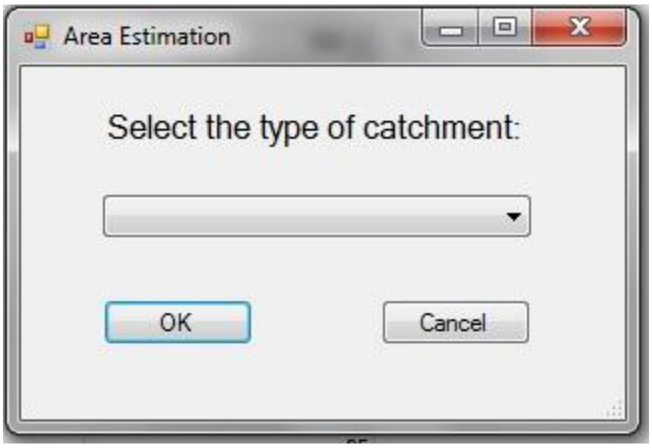


Figure 10: The Area Estimation Window

Table 3: System distributions for different catchment types. The values are derived from [8]

Catchment Type	Distribution (%)			
	Garden/Open Space	Pavement	Roofs	Roads
Central Business District	20	10	50	20
Semi-Detached Housing	20	10	60	10
Detached Housing	60	10	10	20
Industrial	70	7	3	20

Table 4: Field capacity for different soil texture types. Adapted from [12]

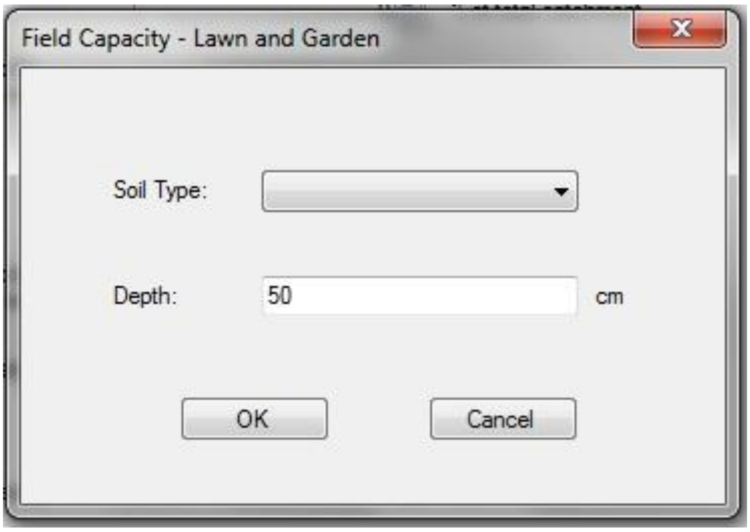
Soil Texture Type	Field Capacity (mm.cm^{-1})
Sand	0.6
Loamy Sand	0.9
Sandy Loam	1.3
Loam	2.0
Poor Structured Clay	1.3
Good Structured Clay	1.9

The other important parameter is the percentage of each impervious surface connected directly to the stormwater system ($\%_{roofconn}$, $\%_{paveconn}$, $\%_{roadconn}$). This means how much of the water flows to stormwater drains and not pervious surfaces such as gardens and lawns. There are default values provided by the software which assume 100% of roads and roofs are connected while only 50% of pavement areas are connected. This last point takes into account driveways and footpaths which often do not flow to a stormwater drain, but rather to a grassed surface.

Under lawns and gardens and bushland, the user is also prompted to enter a value for the soil moisture capacity ($d_{SMC_{lawn}}$ and $d_{SMC_{bush}}$ respectively). This is used in the determination of evapotranspiration from the soil and ultimately the proportion of rainfall that is absorbed by the soil. The values should be given as the depth in mm of moisture capacity. Where users are uncertain what values to use, the “Use Estimate” button calculate and estimate. Clicking this button will open the Field Capacity Window similar to that seen in Figure 11. Here the user can select the soil type based on texture. The choices and the field capacity values associated with them are shown in Table 4. These values are multiplied by the root zone depth to give an overall estimate for the field capacity in mm. The root zone depth can be entered by the user in the Field Capacity Window and is given in cm. Default values are provided as 50 cm for lawns and gardens and 250cm for bushland.

The final piece of information in the surface tab of the Storm Water Catchment Window is the evapotranspiration crop coefficients ($k_{c_{lawn}}$ and $k_{c_{bush}}$). These need only be an estimate based around the pan evaporation method. Clicking the “Use Estimate” button will place the estimates of 0.8 for lawns/gardens (estimated from upper value given in [9]) and 1.46 for bushland (estimated for a eucalypt forest from [10, 11], this has been updated in version 1.006) into their respective textboxes.

Table 4 shows the field capacity values in mm.cm^{-1} used in the determination of field capacity in the storm water catchment. Values have been derived from [12]. This data was updated in version 1.006 of the Sports Field Irrigation Software.



Depth: 50 cm

Figure 11: The Field Capacity Window

The Subsurface Tab of the Storm Water Catchment Window contains prefilled information on groundwater and sewage flows and ultimately determines base flow into the stormwater system and the losses of water during peak flow (wet weather events).

Under ground water constants, the base flow index (k_{BFI}) is effectively a measure of the percentage of water, beyond the field capacity of a soil that enters the groundwater table. This value is dependent on the geology of the area. There are two main geological classes in Melbourne: tertiary basalt and Silurian/Devonian sedimentary. Estimates for the base flow for Victoria were obtained from Lacey and Grayson [13]. This gave values for the base flow index of 0.65 and 0.4 respectively. While the software comes prefilled with the value of 0.55 which is routinely used in the literature [14], estimates can be used by clicking the “Use Estimate” button. This will open the Estimate Base Flow Index Window (shown in Figure 12) where the user can select a location based on either “Eastern Melbourne” or “Western Melbourne.” As the geological formations in the western suburbs tend to be dominated by tertiary basalt a value of 0.65 will be used for this selection. Conversely the eastern suburbs tend to be defined geologically more as Silurian/Devonian sedimentary geology and a value of 0.4 is used for the base flow index here. It should be noted that Lacey and Grayson [13] saw significant variation in the base flow index for different geological ages and land coverage so there will be some error in these estimates.

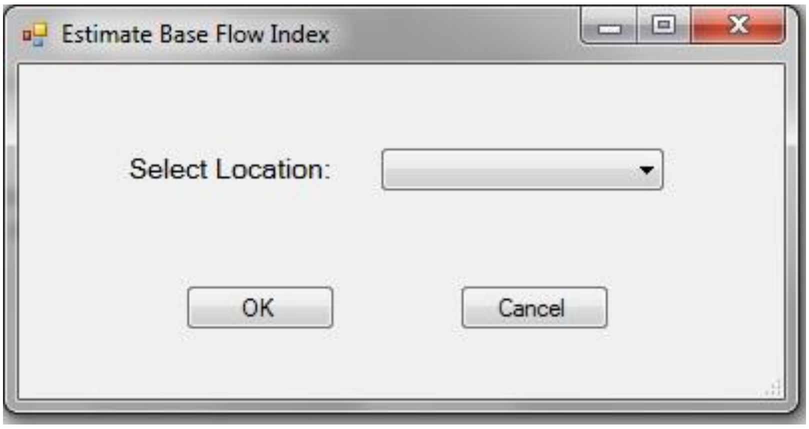


Figure 12: The Estimate Base Flow Index Window

The base flow recession constant ($k_{baseflow}$) defines the percentage of water that infiltrates into the storm water system from the ground water reservoir. A estimate of 0.02 is used for this and has been adapted from [14]. This value was updated for version 1.005 of the software.

The sewer inflows and infiltration ($f_{sewerinflow}$ and k_{II}) refer to the water that enters sewers directly or through percolation into reservoirs around sewer lines. The infiltration index is a measure of the percentage of excess water that enters this separate ground water store. It is generally important for sewer modelling but is retained here for completeness. It has a default value of 0.095 as previously defined in the literature [14].

The percentage of surface runoff as sewer inflow refers primarily to the illegal connection (deliberate or otherwise) of stormwater systems. This value should generally be determined independently, however an estimate of 3% is often used in the literature [14] and this is reflected in the default value.

2.6 Grey Water Window

The Grey Water Window opens when grey water is selected at the starting page. It consists of three main tabs shown in Figure 13 to Figure 15.

The first tab, shown in Figure 13, is for users that know the quality and quantity of grey water that will be available to the project. Similar to previous windows it allows for the volume available to be entered or unlimited to be selected. The water may be shandied with potable and the percentage of grey water in the final irrigation water can be selected. Concentrations of sodium, potassium, magnesium, calcium, total nitrogen and total phosphorus may be entered (all in ppm) along with a dissolved solids concentration (in ppm) or conductivity (in mS.cm^{-1}). Where these are not known a estimate, shown in Table 5, can be selected as an estimate. The tank volume can be specified if desired by the user by checking the model tank volume checkbox and entering the volume in kL in the adjacent text box. The software can also optimize this volume or storage by selecting the optimize checkbox and then specifying a volumetric reliability for the irrigation.

A treatment train for grey water is also required. The options at this window are:

- None
- Wetlands
- Wetlands and Disinfection
- Screening, Grit Removal, Sedimentation, Activated Sludge, Disinfection
- Screening, Grit Removal, Flocculation, Activated Sludge, Disinfection

Table 5: Estimates for grey water quality. Adapted from [15]

Parameter	Estimate	Form
Sodium	70	
Potassium	15	
Magnesium	15	
Calcium	30	
Dissolved Solids	0.081	Conductivity
Nitrogen	12.5	Total Nitrogen
Phosphorus	8	Total Phosphorus

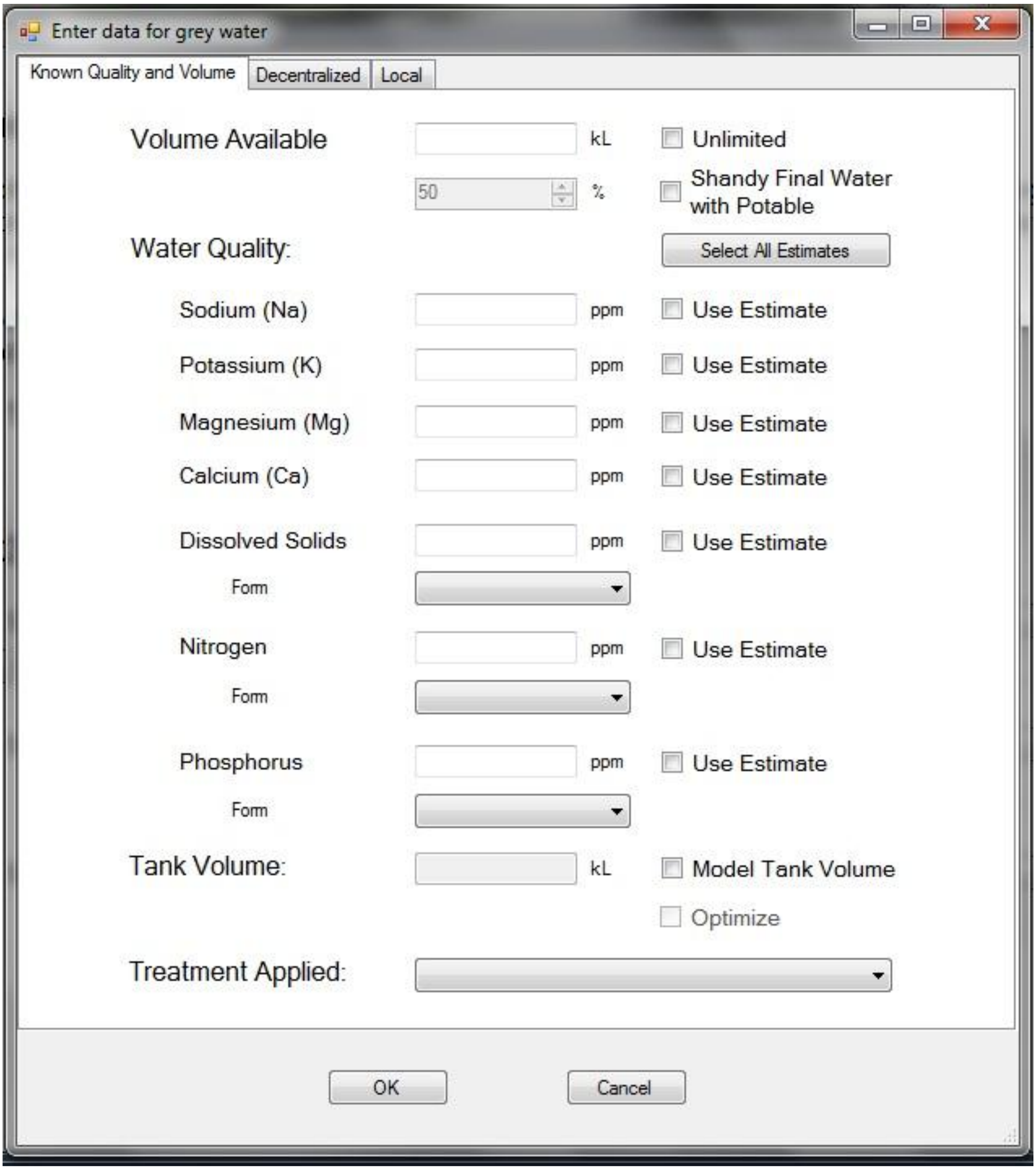
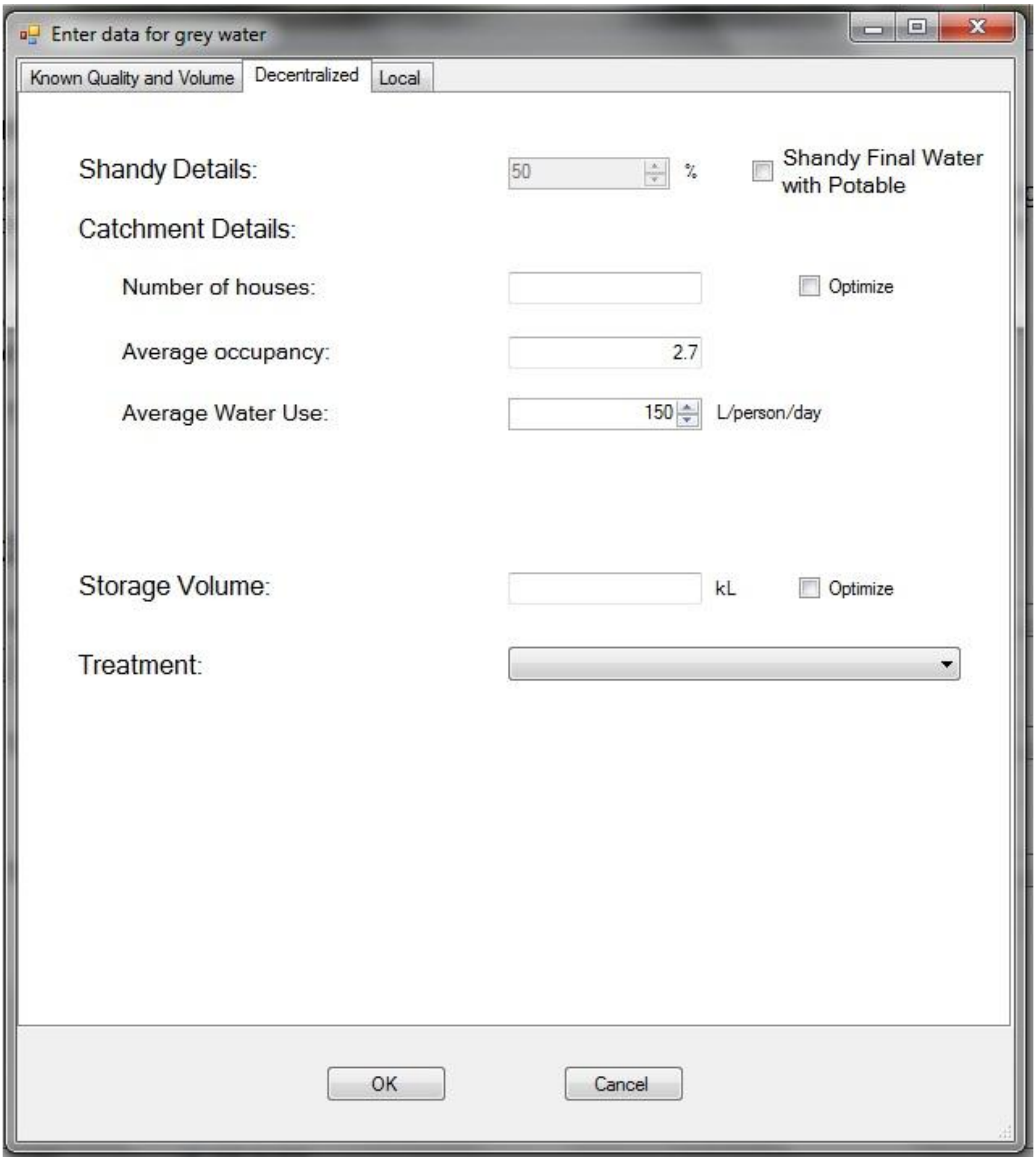


Figure 13: The Known Quality/Quantity Tab of the Grey Water Window



Shandy Details: 50 %

☐ Shandy Final Water with Potable

Catchment Details:

Number of houses: ☐ Optimize

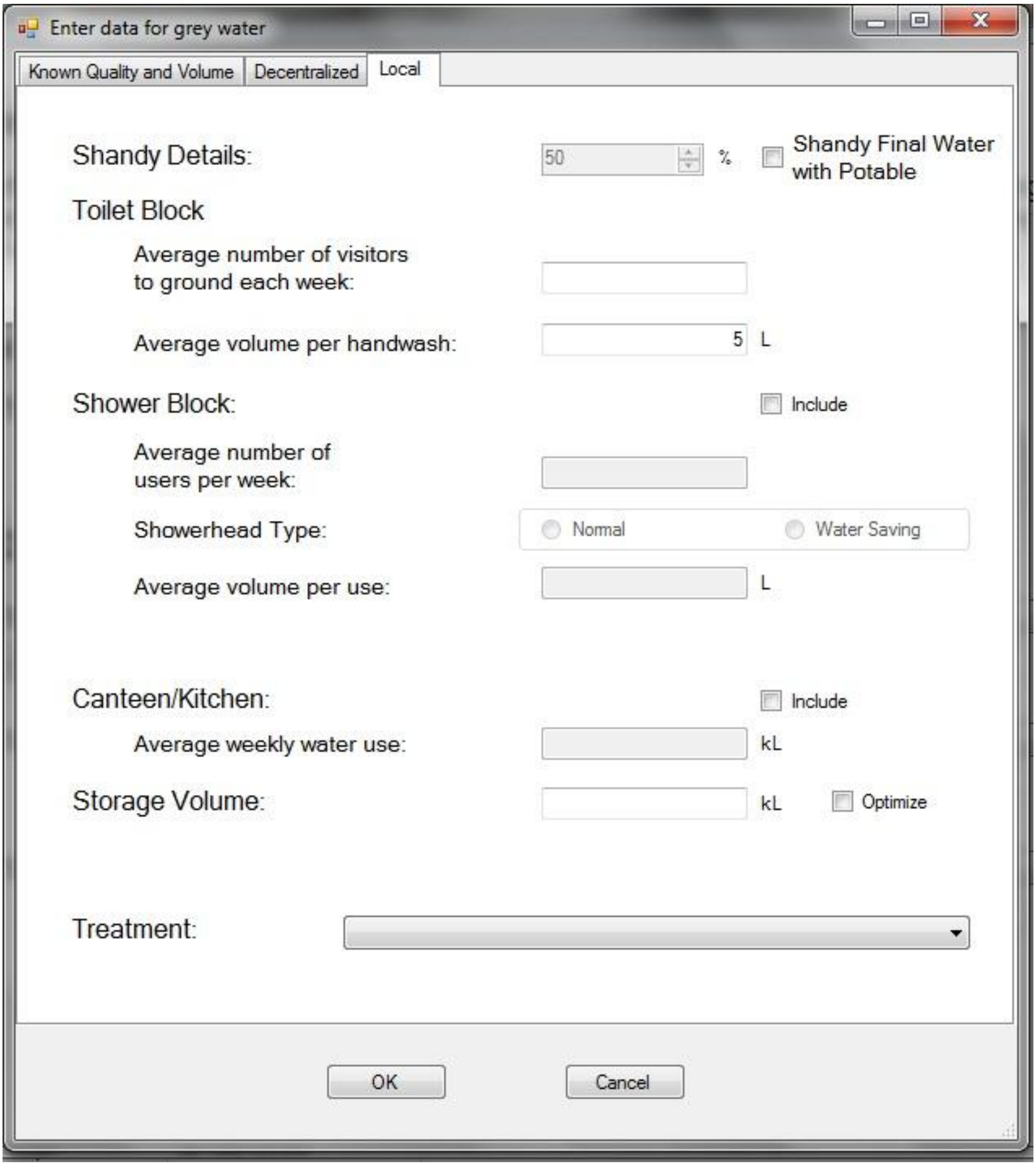
Average occupancy: 2.7

Average Water Use: 150 L/person/day

Storage Volume: kL ☐ Optimize

Treatment:

Figure 14: The Decentralized Tab of the Grey Water Window



Shandy Details: 50 % ☐ Shandy Final Water with Potable

Toilet Block

Average number of visitors to ground each week:

Average volume per handwash: 5 L

Shower Block: ☐ Include

Average number of users per week:

Showerhead Type: ○ Normal ○ Water Saving

Average volume per use: L

Canteen/Kitchen: ☐ Include

Average weekly water use: kL

Storage Volume: kL ☐ Optimize

Treatment:

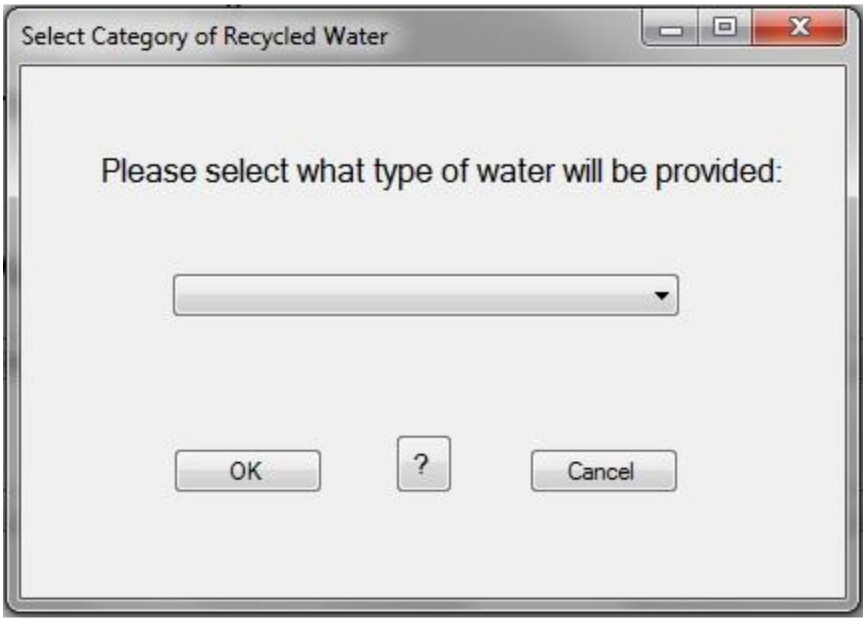
Figure 15: The Local Tab of the Grey Water Window

The second tab of the grey water window (see Figure 14) is for decentralized grey water systems. That is to say it is associated with collection of grey water from a small community and treating the water onsite for reuse. This option is potentially expensive but has been demonstrated in Europe and the Middle East in the past using an appropriate treatment technology [16, 17]. In this window the user provides details on the catchment as well as treatment and storage considerations. The number of houses (n_{houses}) in the catchment must be specified along with the average occupancy ($n_{occupancy}$) and the average water use. Checking to optimize checkbox will allow the model to alter the number of houses in the catchment to reach the desired volumetric reliability (ρ_{aim}). Similarly the storage volume can be optimized for the desired reliability. The average occupancy and average water use come prefilled at 2.7 and 150 L.person^{-1}.day^{-1} respectively. A treatment train also must be selected. The options here are the same as the first tab.

The third tab of the grey water window (see Figure 15) is for local grey water recycling systems. Here it is meant that water is taken from sources on site (i.e. toilet blocks, shower blocks and kitchens) and treated on site for reuse. If the water is due to be shandied with potable water the corresponding checkbox can be checked and the percentage of grey water in the final irrigation water ($\%_{shandy}$) can be specified. From there the average number of visitors to the ground ($n_{visitors}$) must be selected along with the average volume of water per handwash ($V_{handwash}$). The last of these comes prefilled with 5 L but may be adjusted by the user. The user must also specify a storage volume ($V_{greytank}$) in kL and the treatment train from the same options as the previous two tabs. With the storage volume the user may also choose to optimize the size of the storage by selecting the corresponding check box and providing the desired volumetric reliability (ρ_{aim}). The user may also select whether to include water from the showerblock and/or the kitchen areas. If the shower block is to be selected the user should check the Include check box next to the shower block heading and then provide details on the average number of users per week ($n_{showerusers}$), the showerhead type and the average volume of water used per shower (V_{shower}). The showerhead type is selected from the options “normal” and “water saving” and assists in providing an estimate for the average volume per use. Once selected this textbox will be filled with the values 98 L for a normal showerhead and 63 L for a water saving showerhead. The value can, however, be changed by the user. If the kitchen areas are selected for inclusion the user should check the Include checkbox next to the Canteen/Kitchen title and provide a value for the weekly water use ($V_{kitchen}$) in kL.

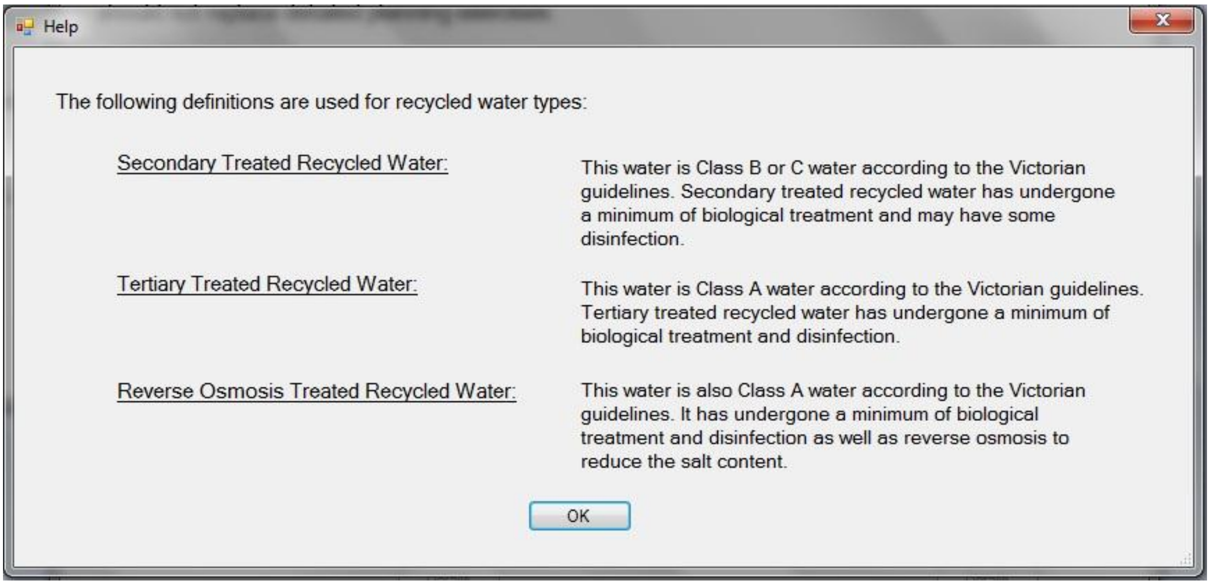
2.7 Centralized Recycled Water Windows

When Centralized Recycled Water is selected from the opening window, the window shown in Figure 16 appears. From here the user must select the type of recycled water that will be provided: secondary treated recycled water, tertiary treated recycled water or MF/RO treated recycled water. These are the three main water types provided by water authorities for irrigation in Australia. The main reason for separating these water types is to simplify to potential treatment techniques that may be applied to the water and make it simpler to provide estimated qualities where required. Clicking the “?” button will display the Recycled Water Help Window, show in Figure 17 that provides descriptions of the three water types.



Please select what type of water will be provided:

Figure 16: The Centralized Recycled Water Window



The following definitions are used for recycled water types:

Secondary Treated Recycled Water:	This water is Class B or C water according to the Victorian guidelines. Secondary treated recycled water has undergone a minimum of biological treatment and may have some disinfection.
Tertiary Treated Recycled Water:	This water is Class A water according to the Victorian guidelines. Tertiary treated recycled water has undergone a minimum of biological treatment and disinfection.
Reverse Osmosis Treated Recycled Water:	This water is also Class A water according to the Victorian guidelines. It has undergone a minimum of biological treatment and disinfection as well as reverse osmosis to reduce the salt content.

Figure 17: The Recycled Water Help Window

Selecting secondary treated wastewater will open the Secondary Treated Recycled Water Window shown in Figure 18. Here the user may provide the volume of water available or select unlimited and choose whether the water is shandied with potable and in what ratio. The user may also provide water quality data as with previous windows or opt to use estimates. These values have been taken from average water qualities for secondary wastewater and are shown in Table 6. The user should also select whether the programme should include a tank in the model by checking the Model Tank Value checkbox. The volume entered can be optimized by checking the Optimize checkbox and choosing the appropriate volumetric reliability. Treatment options can also be explored using the dropdown menu. The options for this water are:

- None
- Microfiltration and Reverse Osmosis

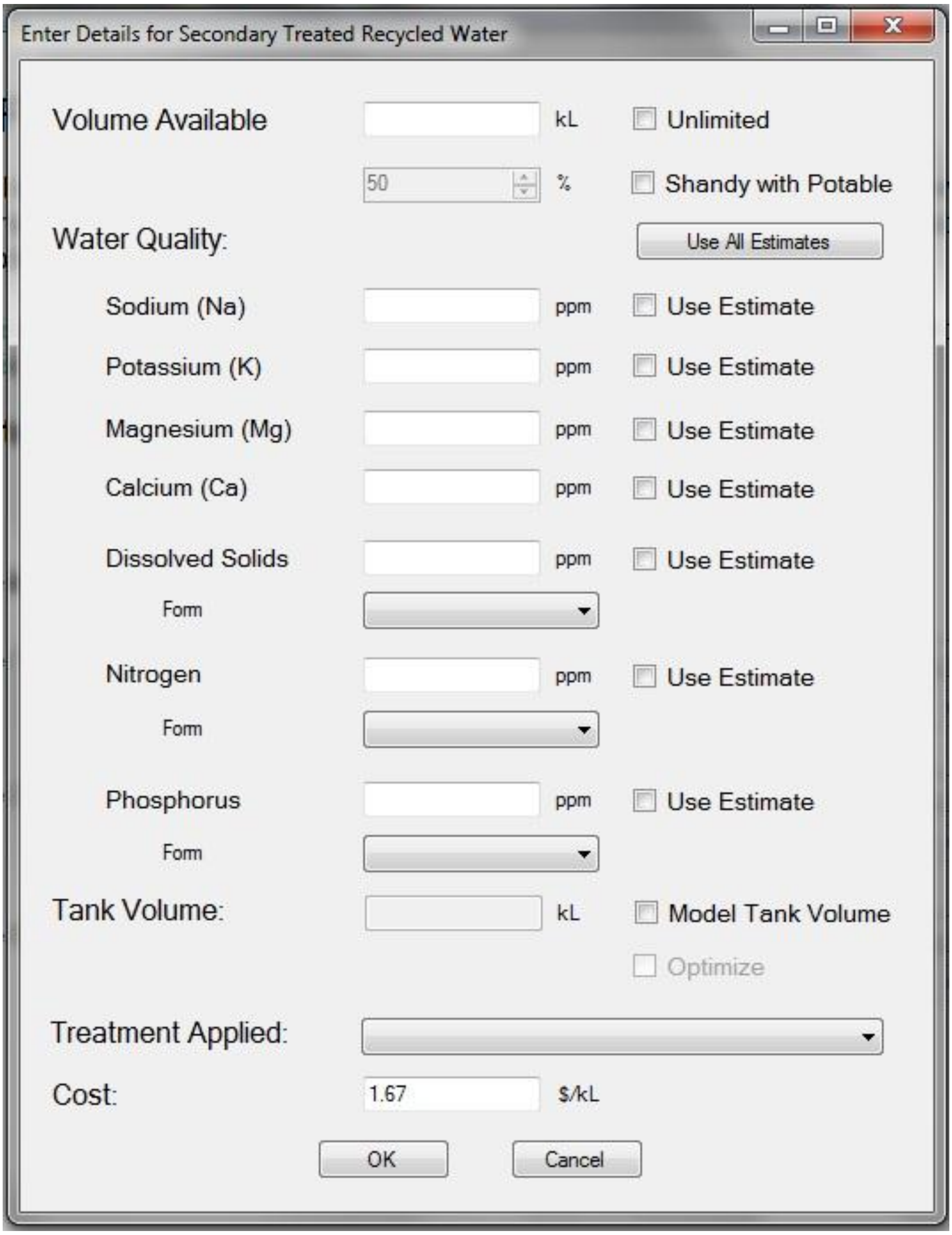
Finally the Cost box allows users to alter the cost from the default value of $1.67.kL^{-1}, estimated from the non-residential recycled water usage charges in Melbourne as of 1 July 2011.

The Tertiary Treated Recycled Water Window (see Figure 19) and Reverse Osmosis Treated Recycled Water Window (Figure 20) are very similar to the secondary one except for the estimates and the treatment options. For tertiary wastewater the user may select either Western Treatment Plant or Eastern Treatment Plant from the drop down box next to the Water Quality title to select the appropriate estimate. The values used here are shown in Table 7. The treatment options for this water are:

- None
- Microfiltration and Reverse Osmosis

As with secondary treated recycled water, there is a Cost box available to users to alter the cost of the water from the default value of $1.67.kL^{-1}. This value was estimated from the non-residential recycled water usage charges for City West Water and South East Water as of 1 July 2011.

RO treated recycled water uses the estimates shown in Table 8. As there were no values available for this water quality in Melbourne at the time of writing, these values were taken from the Kwinana Water Reclamation Plant south of Perth. There are also no treatment options available for this water due to its high quality. The cost is set to a default of $1.90.kL^{-1} and is based on the assumption that the charges would be approximately 95% the cost of potable water.



Enter Details for Secondary Treated Recycled Water

Volume Available kL ☐ Unlimited

50 % ☐ Shandy with Potable

Water Quality: Use All Estimates

Sodium (Na) ppm ☐ Use Estimate

Potassium (K) ppm ☐ Use Estimate

Magnesium (Mg) ppm ☐ Use Estimate

Calcium (Ca) ppm ☐ Use Estimate

Dissolved Solids ppm ☐ Use Estimate

Form

Nitrogen ppm ☐ Use Estimate

Form

Phosphorus ppm ☐ Use Estimate

Form

Tank Volume: kL ☐ Model Tank Volume

☐ Optimize

Treatment Applied:

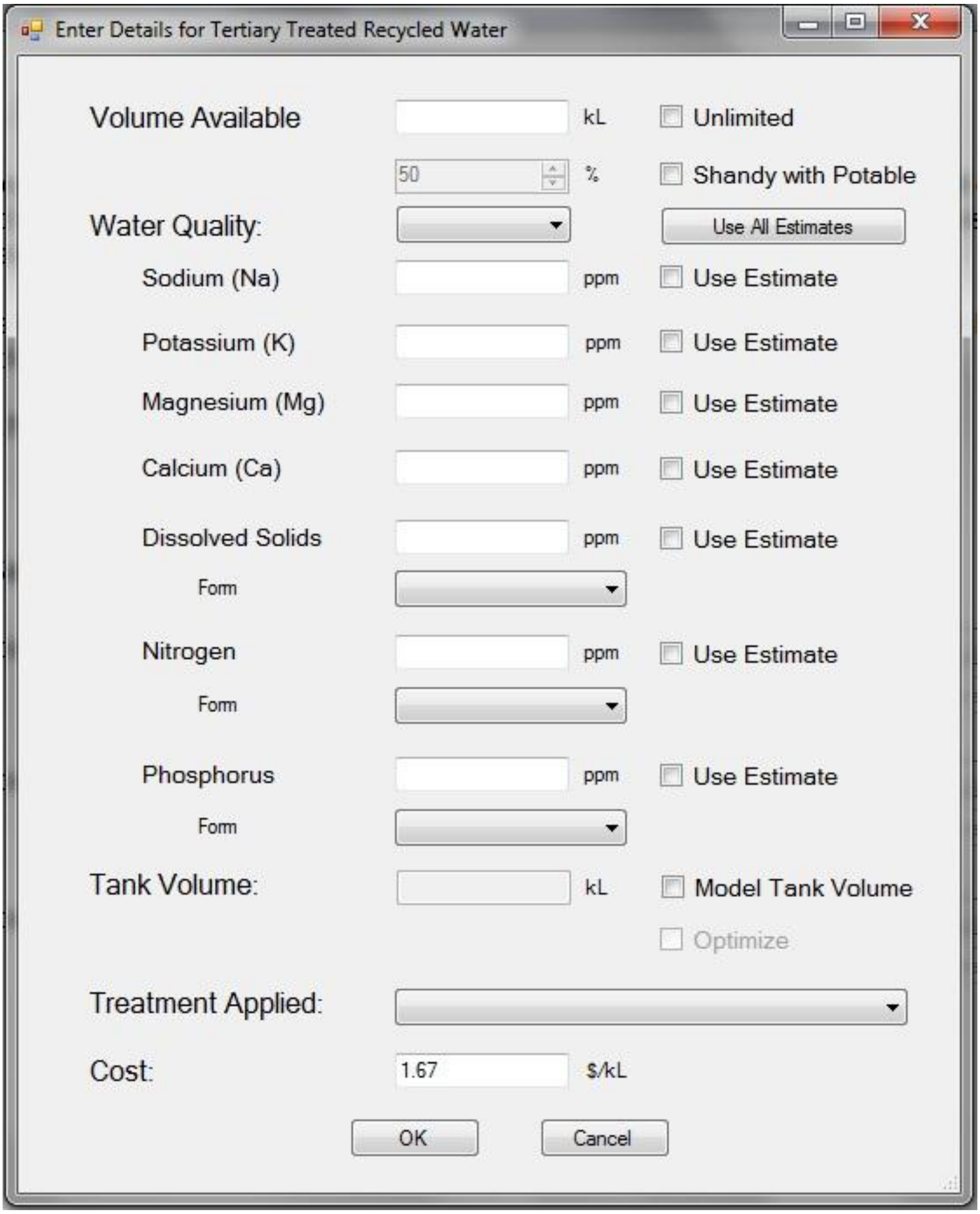
Cost: 1.67 $/kL

OK Cancel

Figure 18: The Secondary Recycled Water Window.

Table 6: Estimates for secondary treated recycled water

Parameter	Estimate	Form
Sodium	70.8 ppm	
Potassium	7 ppm	
Magnesium	6.61 ppm	
Calcium	24.1 ppm	
Dissolved Solids	495 ppm	Total Dissolved Solids
Nitrogen	12.5 ppm	Total Nitrogen
Phosphorus	8 ppm	Total Phosphorus



Enter Details for Tertiary Treated Recycled Water

Volume Available ____ kL ☐ Unlimited

50 % ☐ Shandy with Potable

Water Quality: [Use All Estimates]

Sodium (Na) ____ ppm ☐ Use Estimate

Potassium (K) ____ ppm ☐ Use Estimate

Magnesium (Mg) ____ ppm ☐ Use Estimate

Calcium (Ca) ____ ppm ☐ Use Estimate

Dissolved Solids ____ ppm ☐ Use Estimate

Form

Nitrogen ____ ppm ☐ Use Estimate

Form

Phosphorus ____ ppm ☐ Use Estimate

Form

Tank Volume: ____ kL ☐ Model Tank Volume

☐ Optimize

Treatment Applied:

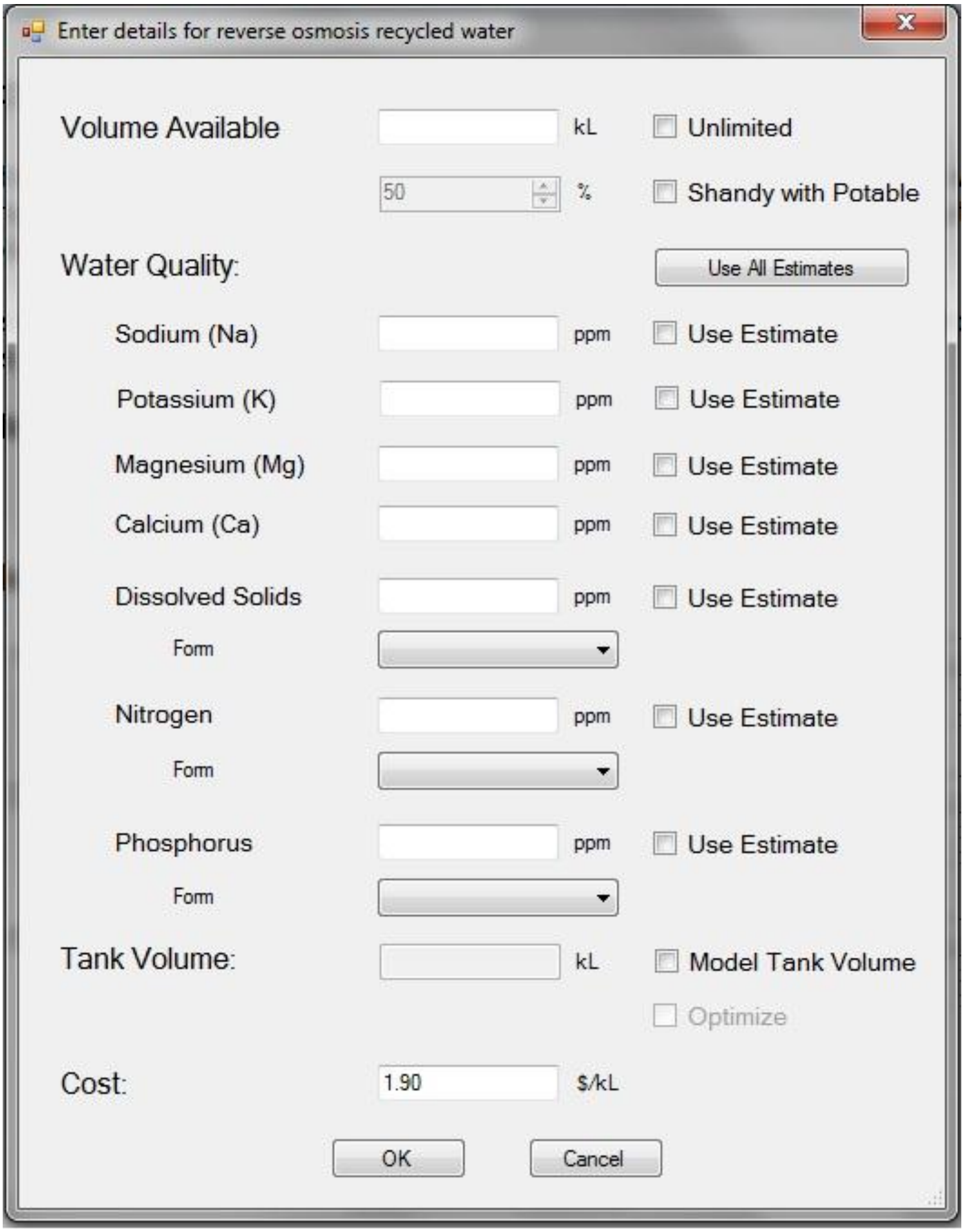
Cost: 1.67 $/kL

[OK] [Cancel]

Figure 19: The Tertiary Recycled Water Window.

Table 7: Estimates for tertiary treated recycled water. Adapted from [18, 19]

Parameter	ETP Value	WTP Value	Form
Sodium (ppm)	100	290	
Potassium (ppm)	20.5	32	
Magnesium (ppm)	9.4	26	
Calcium (ppm)	18.5	36	
Dissolved Solids	0.918 $mS.cm^{-1}$	1.9 $mS.cm^{-1}$	Conductivity
Nitrogen (ppm)	21	21	Total Nitrogen
Phosphorus (ppm)	8.1	8.1	Total Phosphorus



50 %

Cost: 1.90 $/kL

Figure 20: The Reverse Osmosis Recycled Water Window.

Table 8: Estimates for RO treated recycled water [20]

Parameter	Estimate	Form
Sodium (ppm)	3.92	
Potassium (ppm)	0.58	
Magnesium (ppm)	0.1	
Calcium (ppm)	0.1	
Dissolved Solids	0.035 $mS.cm^{-1}$	Conductivity
Nitrogen (ppm)	0.3	Total Nitrogen
Phosphorus (ppm)	0.17	Total Phosphorus

2.8 Decentralized Recycled Water Window

Where decentralized recycled water is selected as an option, the Decentralized Recycled Water Window will be opened. This is essentially for treatment of raw sewage for reuse and is applicable for sewer mining operations and during the establishment of new decentralized recycled water project (typically in new developments). The window consists of three tabs, similar to the Grey Water Window and these are generally similar to those already seen. The first tab (shown in Figure 21) is reserved for known volumes and qualities of raw sewage similar to a sewer mining operation. The data fields are the same as previous windows, the main differences are in the estimates and treatment options. The estimates have been taken from data published for Melbourne and assumes the sewage comes only from residential sources [21]. They are shown in Table 9. The treatment options for this tab are:

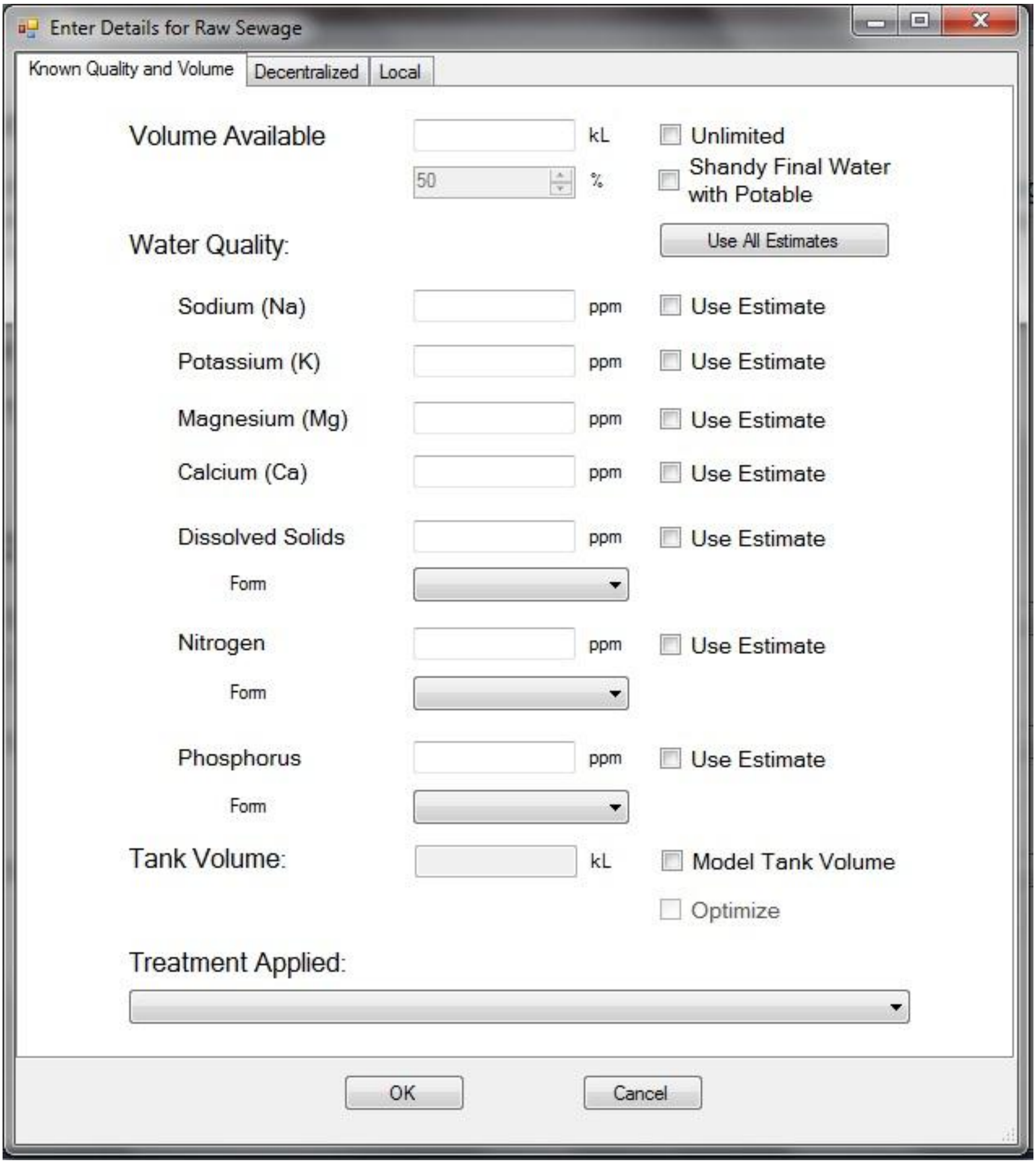
- Biological Nutrient Removal, Rapid Sand Filtration, Granular Activated Carbon, Disinfection
- Screening, Grit Removal, Flocculation, Activated Carbon, Rapid Sand Filtration, Granular Activated Carbon, Disinfection
- Screening, Grit Removal, Floccuation, Activated Carbon, Disinfection
- Biological Nutrient Removal, Rapid Sand Filtration, Granular Activated Carbon, Microfiltration, Reverse Osmosis, Disinfection
- Screening, Grit Removal, Flocculation, Activated Carbon, Rapid Sand Filtration, Granular Activated Carbon, Microfiltration, Reverse Osmosis, Disinfection
- Screening, Grit Removal, Floccuation, Activated Carbon, Microfiltration, Reverse Osmosis, Disinfection

The second tab investigates decentralized recycled water, looking at a small residential catchment, shown in Figure 22. It requires the same detail as the decentralized tab in the Grey Water Window. It also allows for the optimization of both the catchment and the water storage based around a selected volumetric reliability. The main difference is in treatment options which are ultimately the same as for the first tab.

The third tab is for local water recycling based around sewage flows from a particular site and is shown in Figure 23. It too is similar to the Local Tab in the Grey Water Window, but has one important differences in that the average flush volume for the toilet block is also required (this is prefilled to 6 L). The treatment options for this tab are the same as other tabs in this window.

Table 9: Estimates for raw sewage in decentralized recycled water systems. Adapted from [21]

Parameter	Estimate	Form
Sodium (ppm)	87.3	
Potassium (ppm)	16.8	
Magnesium (ppm)	4.93	
Calcium (ppm)	9.26	
Dissolved Solids	375 ppm	Total Dissolved Solids
Nitrogen (ppm)	57	Total Nitrogen
Phosphorus (ppm)	7.3	Total Phosphorus



Enter Details for Raw Sewage

Known Quality and Volume | Decentralized | Local

Volume Available kL ☐ Unlimited
50 % ☐ Shandy Final Water with Potable

Water Quality: Use All Estimates

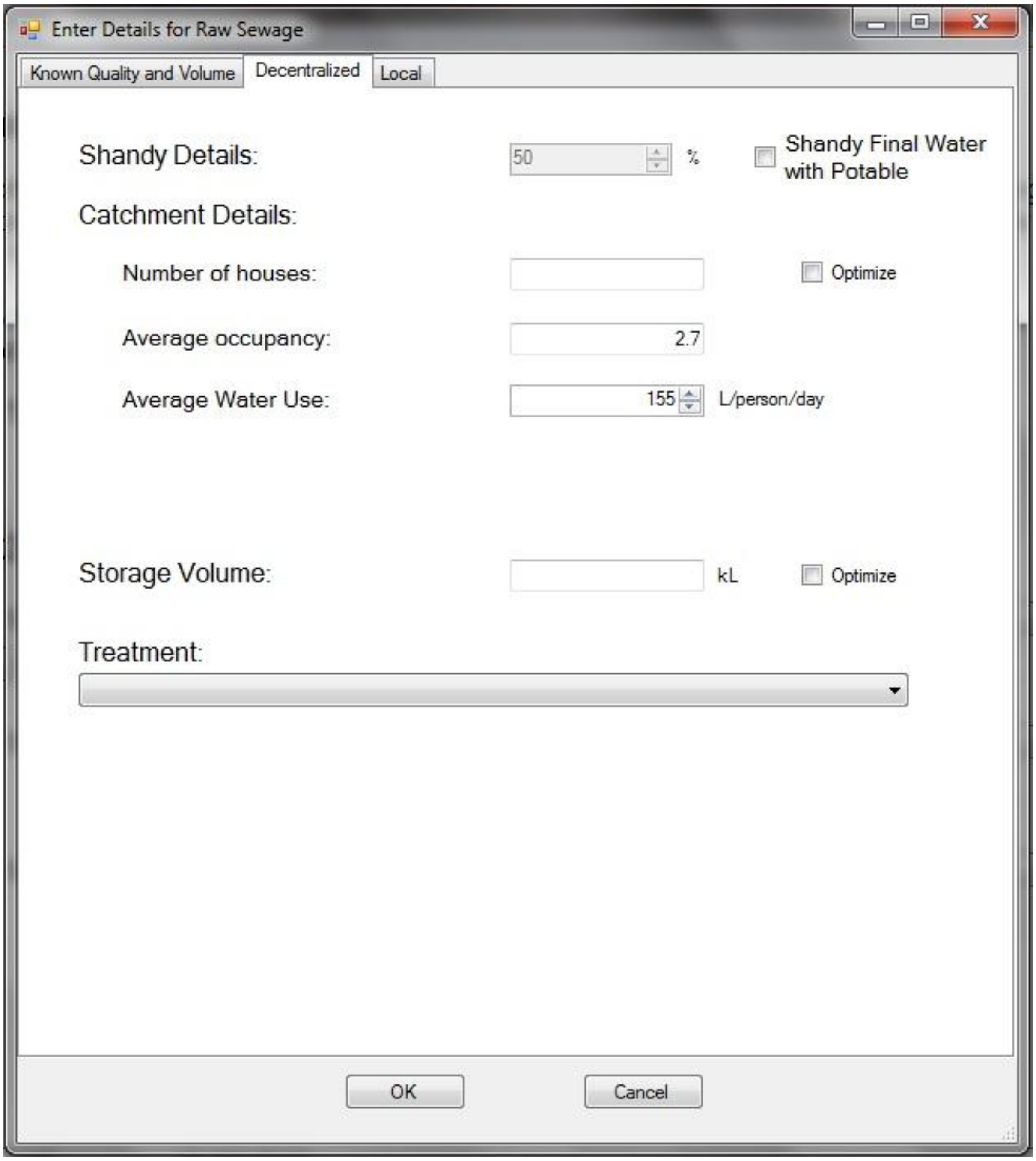
Sodium (Na) ppm ☐ Use Estimate
Potassium (K) ppm ☐ Use Estimate
Magnesium (Mg) ppm ☐ Use Estimate
Calcium (Ca) ppm ☐ Use Estimate
Dissolved Solids ppm ☐ Use Estimate
Form
Nitrogen ppm ☐ Use Estimate
Form
Phosphorus ppm ☐ Use Estimate
Form

Tank Volume: kL ☐ Model Tank Volume
☐ Optimize

Treatment Applied:

OK Cancel

Figure 21: The Known Quality/Volume Tab of the Decentralized Recycled Water Window



Shandy Details: 50 %

☐ Shandy Final Water with Potable

Catchment Details:

Number of houses: ☐ Optimize

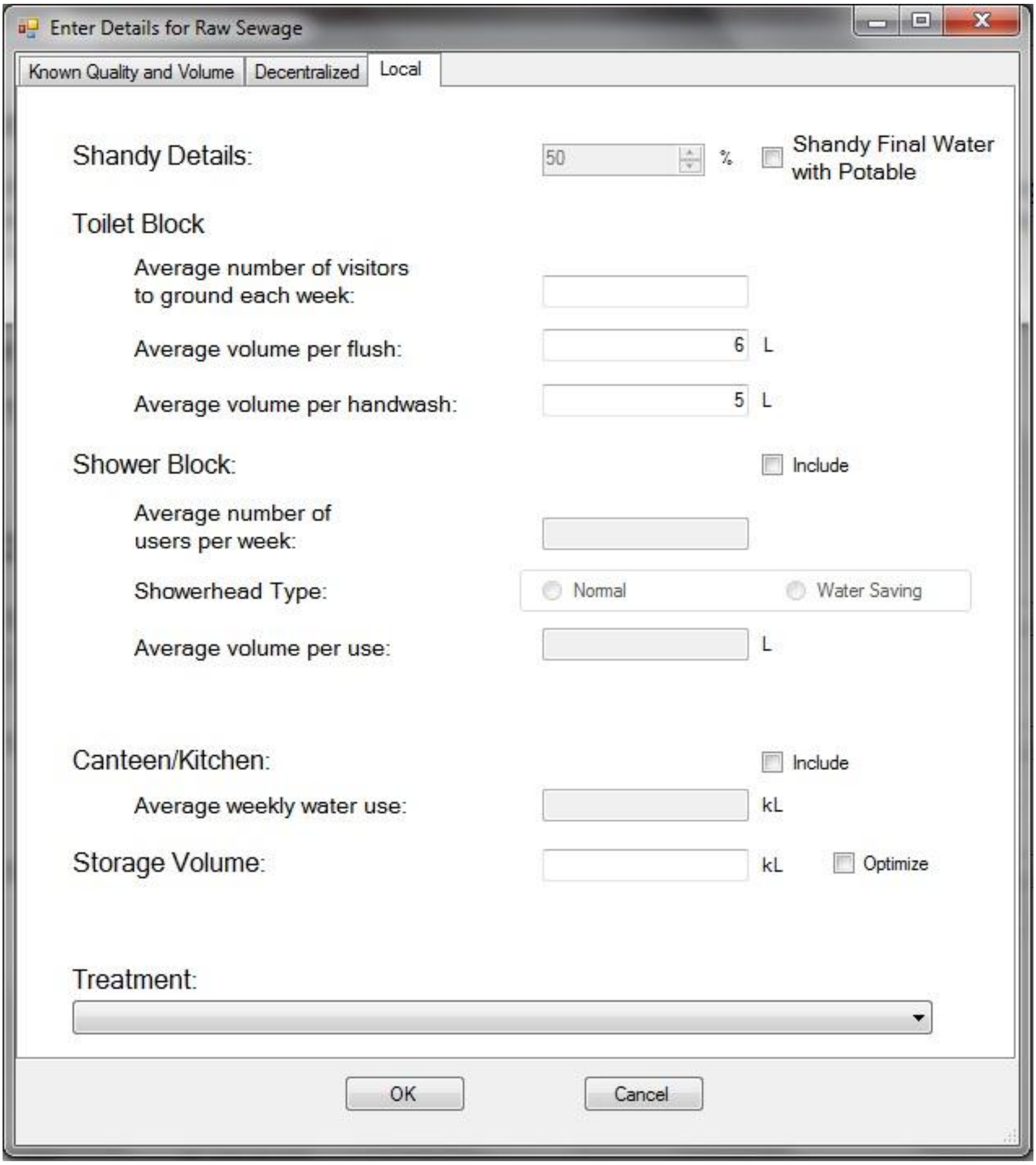
Average occupancy: 2.7

Average Water Use: 155 L/person/day

Storage Volume: kL ☐ Optimize

Treatment:

Figure 22: The Decentralized Tab of the Decentralized Recycled Water Window



Shandy Details: 50 % ☐ Shandy Final Water with Potable

Toilet Block

Average number of visitors to ground each week:

Average volume per flush: 6 L

Average volume per handwash: 5 L

Shower Block: ☐ Include

Average number of users per week:

Showerhead Type: ○ Normal ○ Water Saving

Average volume per use: L

Canteen/Kitchen: ☐ Include

Average weekly water use: kL

Storage Volume: kL ☐ Optimize

Treatment:

Figure 23: The Local Tab of the Decentralized Recycled Water Window

2.9 Ground Water Window

Where ground water is selected as a water source the Ground Water Window (shown in Figure 24) will open. This window is similar to the Centralized Recycled Water Windows in the information required. The main difference is in the estimates for water quality and the treatment options available. Table 10 shows the estimates for Ground Water. These values were obtained from publication on groundwater in the foothills of the Dandenong Ranges [22]. The treatment available for selection through this window are:

- None
- Aeration, Rapid Sand Filtration
- Aeration, Microfiltration
- Aeration, Microfiltration, Reverse Osmosis
- Aeration, Rapid Sand Filtration, Granular Activated Carbon, Reverse Osmosis
- Aeration, Microfiltration, Ion Exchange
- Aeration, Rapid Sand Filtration, Ion Exchange

Table 10: Estimates for groundwater [22]

Parameter	Estimate	Form
Sodium (ppm)	35	
Potassium (ppm)	3.3	
Magnesium (ppm)	6	
Calcium (ppm)	84	
Dissolved Solids	0.713 $mS.cm^{-1}$	Conductivity
Nitrogen (ppm)	4.35	Total Nitrogen
Phosphorus (ppm)	0	Total Phosphorus

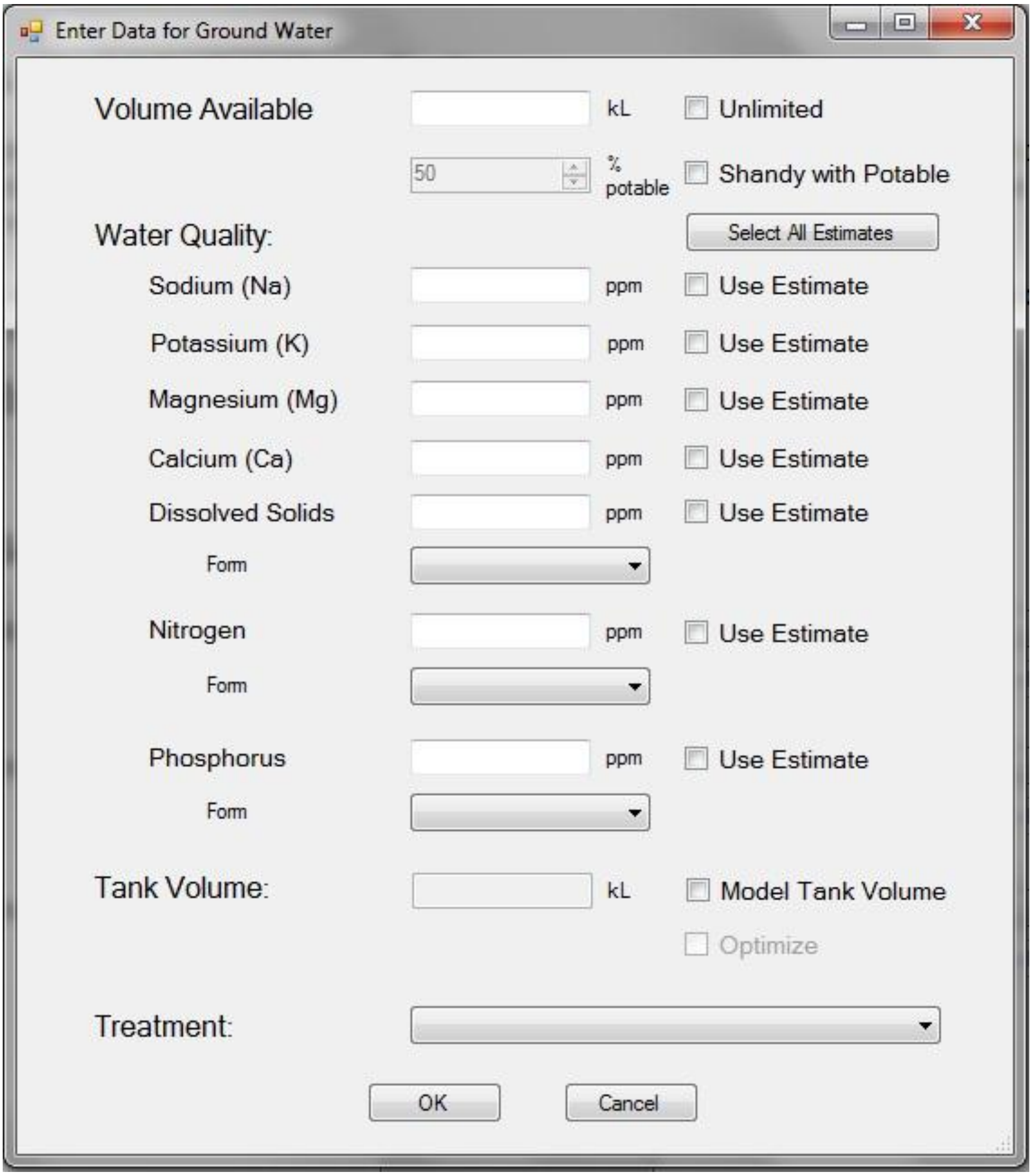


Figure <?>: The Ground Water Window

Table 11: Estimates for brackish water (currently based on groundwater) [22]

Parameter	Estimate	Form
Sodium (ppm)	36	
Potassium (ppm)	3.3	
Magnesium (ppm)	6	
Calcium (ppm)	84	
Dissolved Solids	0.713 $mS.cm^{-1}$	Conductivity
Nitrogen (ppm)	4.35	Total Nitrogen
Phosphorus (ppm)	0	Total Phosphorus

2.10 Brackish Water Window

Where brackish water is selected as a water source, the Brackish Water Window, shown in Figure 25, will open. This window is similar to the Ground Water Window in terms of the information required, but uses different estimates for water qualities and difference treatment options. The estimates used for this window were taken from literature values and are shown in Table 11. The treatment options available through this window are:

- None
- Screening, Rapid Sand Filtration
- Screening, Microfiltration, Reverse Osmosis

2.11 Seawater Window

The Seawater Window (shown in Figure 26) will open when seawater is selected as a water source. It is essentially the same as the Brackish Water Window except for the estimates and the addition of some treatment options. The estimates for water qualities have been taken from the literature and are shown in Table 12. It should be noted that the water quality specifies seawater quality not treated water and care should be taken to ensure that this is what is entered by a user where the estimate is not employed. The treatment options for this window are:

- None
- Screening, Microfiltration, Reverse Osmosis
- Screening, Microfiltration, Double Pass Reverse Osmosis

Table 12: Estimates for sea water

Parameter	Estimate	Form
Sodium (ppm)	10900	
Potassium (ppm)	390	
Magnesium (ppm)	1310	
Calcium (ppm)	410	
Dissolved Solids	53.174 $mS.cm^{-1}$	Conductivity
Nitrogen (ppm)	0.6	Total Nitrogen
Phosphorus (ppm)	0.06	Total Phosphorus

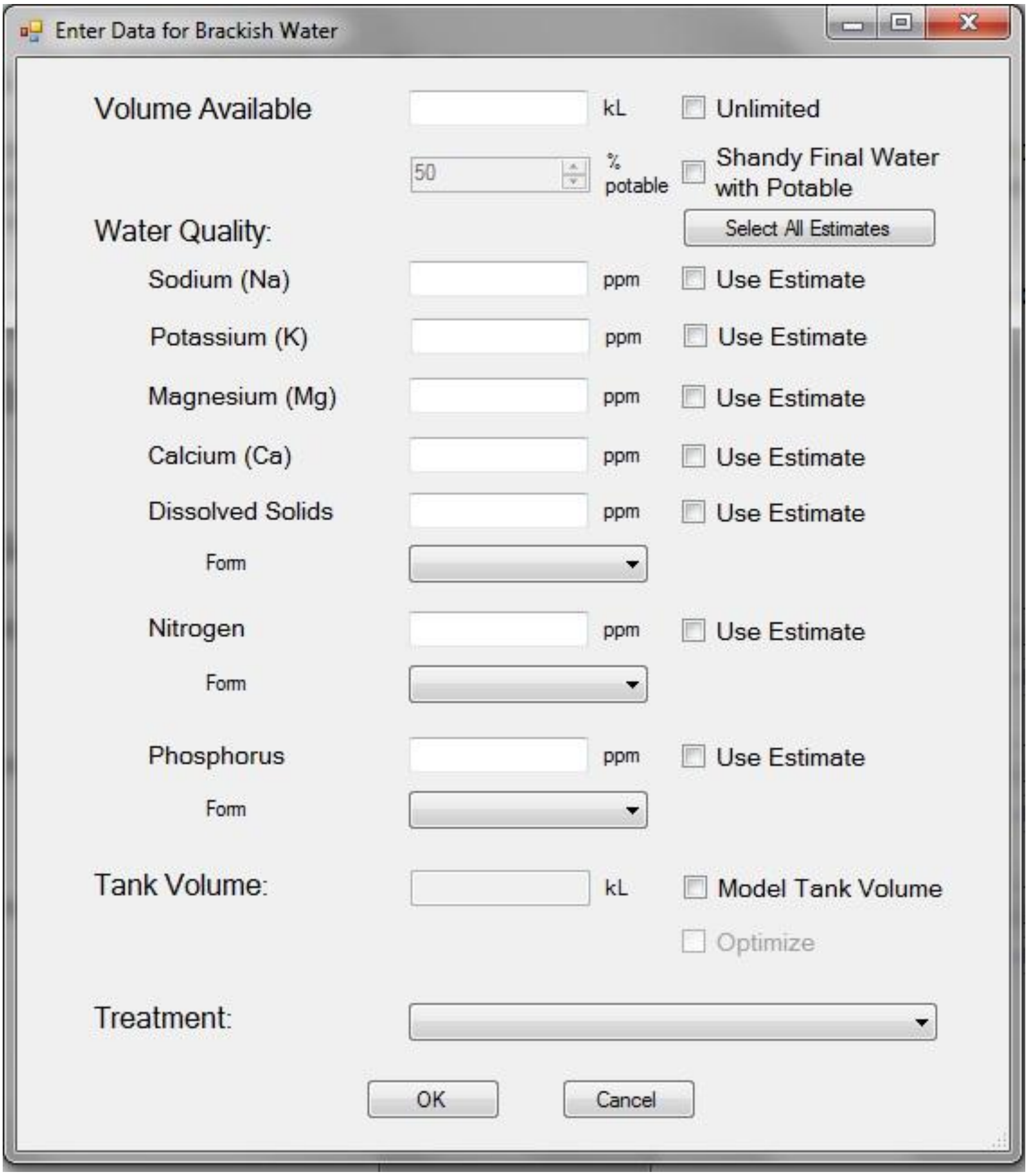


Figure 25: The Brackish Water Window

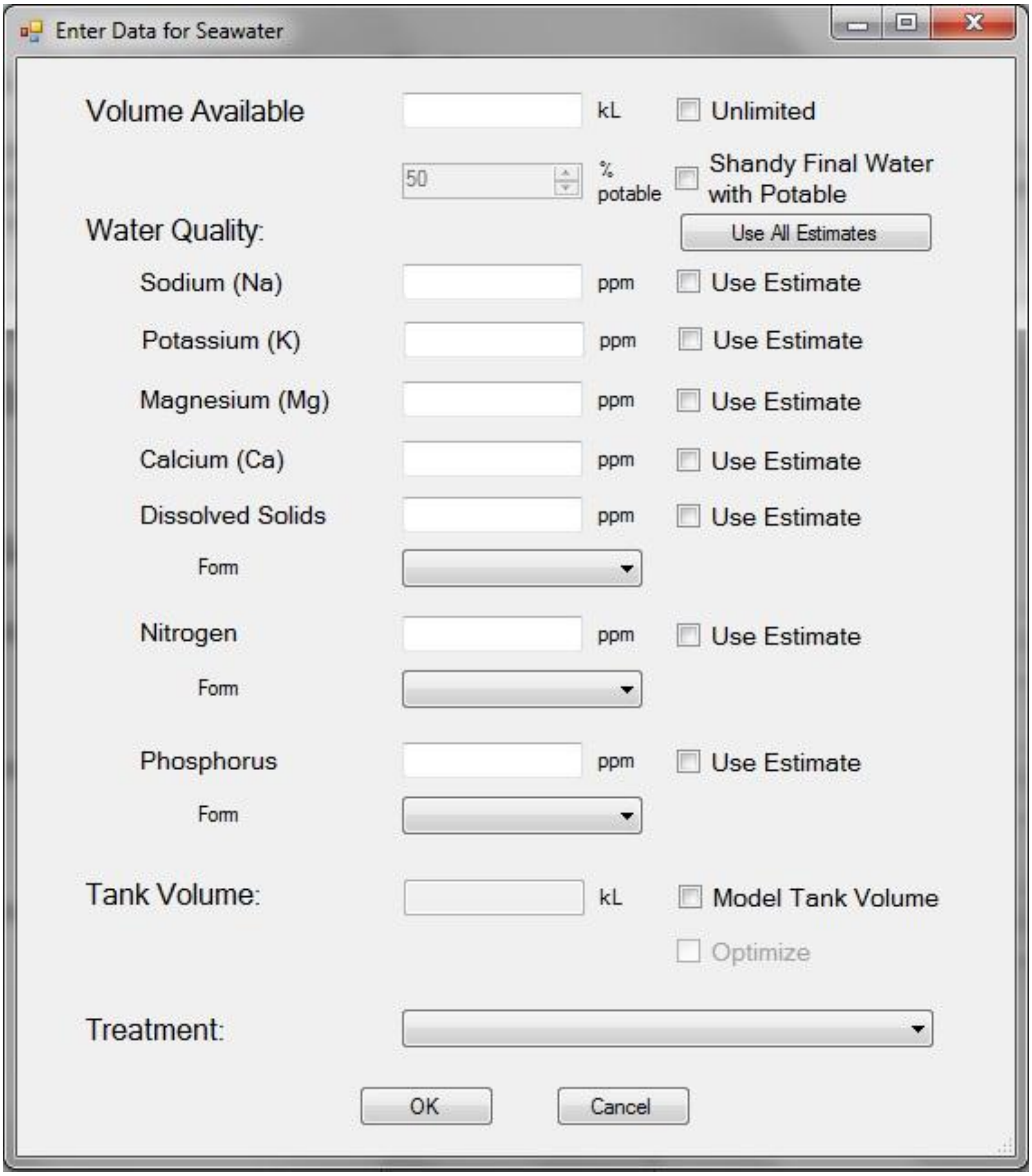


Figure 26: The Sea Water Window

2.12 Custom Window

When a custom water source is required custom selection from the drop down menu of the front page will open the Custom Window, shown in Figure 27. This selection is only for alternative sources where all possible information about the water is known. This is similar to the other simple windows with some important exceptions: (i) there are no estimates as water qualities cannot be estimated, (ii) there are no treatment options as treatment trains cannot be recommended where the water quality is unknown and (iii) shandying the water with potable water is not available.

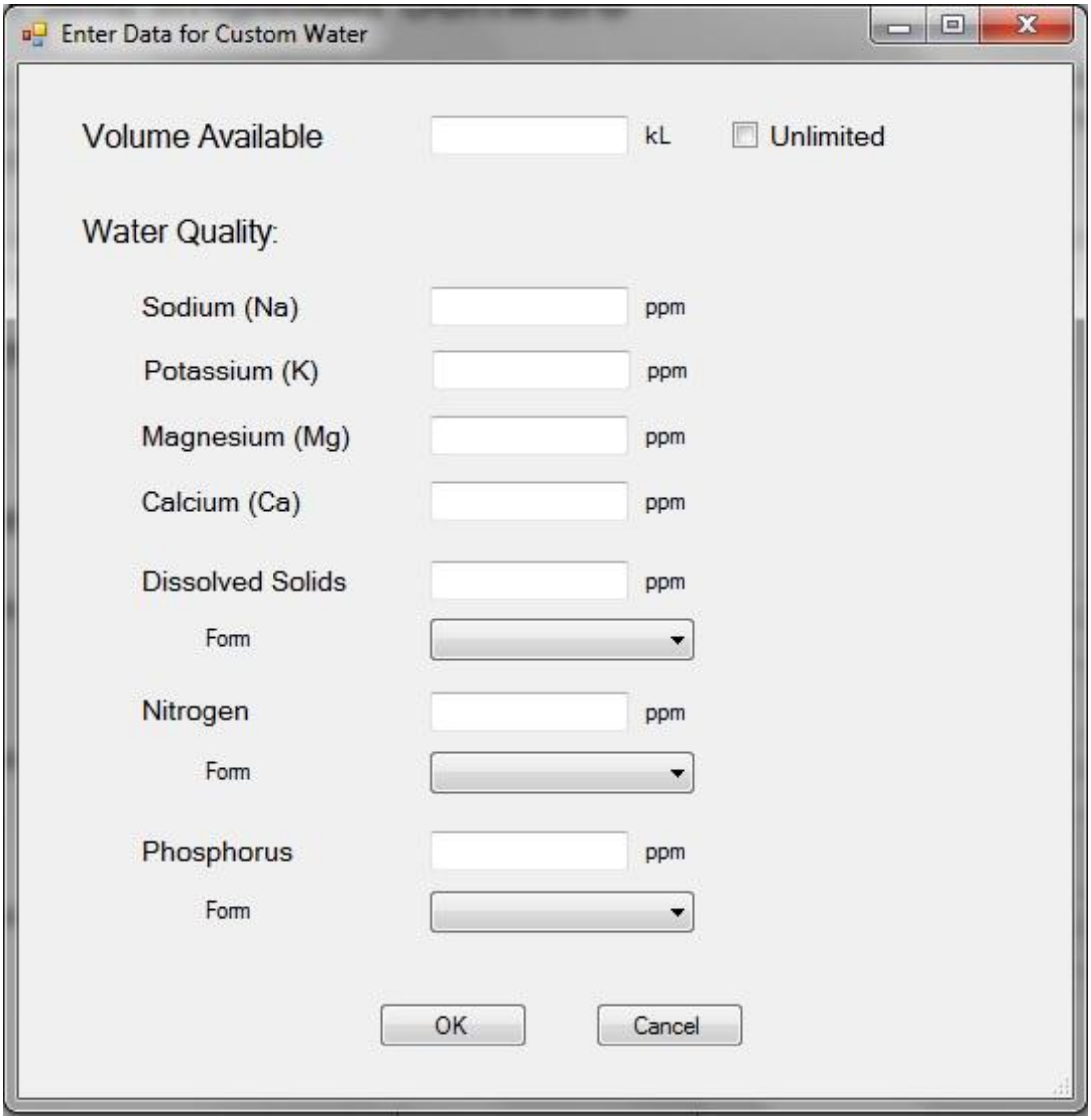


Figure 27: The Custom Water Window

3. Overview of the Programme – Model

3.1 Water Demand

To develop this model water requirements were considered on a daily basis based on previous ten years' data. The way of doing this is pictorially described in Figure 28. Ultimately, the soil acts as a reservoir of water that is available to the turf. Rainfall will fill this reservoir until it is full and overflow will occur, either as runoff or through percolation of the soil. The reservoir will be depleted through use in the form of evapotranspiration (i.e. transpiration (or use) by the turf in growth and evaporation from the soil). When the reservoir is depleted, extra water must be added in the form of irrigation. The size of the reservoir is dependent on the soil type and the type of growth required [23]. The evapotranspiration is dependent on the turf type and the type of growth required (or available moisture) [23]. The ratio of percolation to runoff is also dependent on soil type, but this is not particularly important when calculating irrigation requirements.

The following section will provide a mathematical explanation of irrigation modelling techniques.

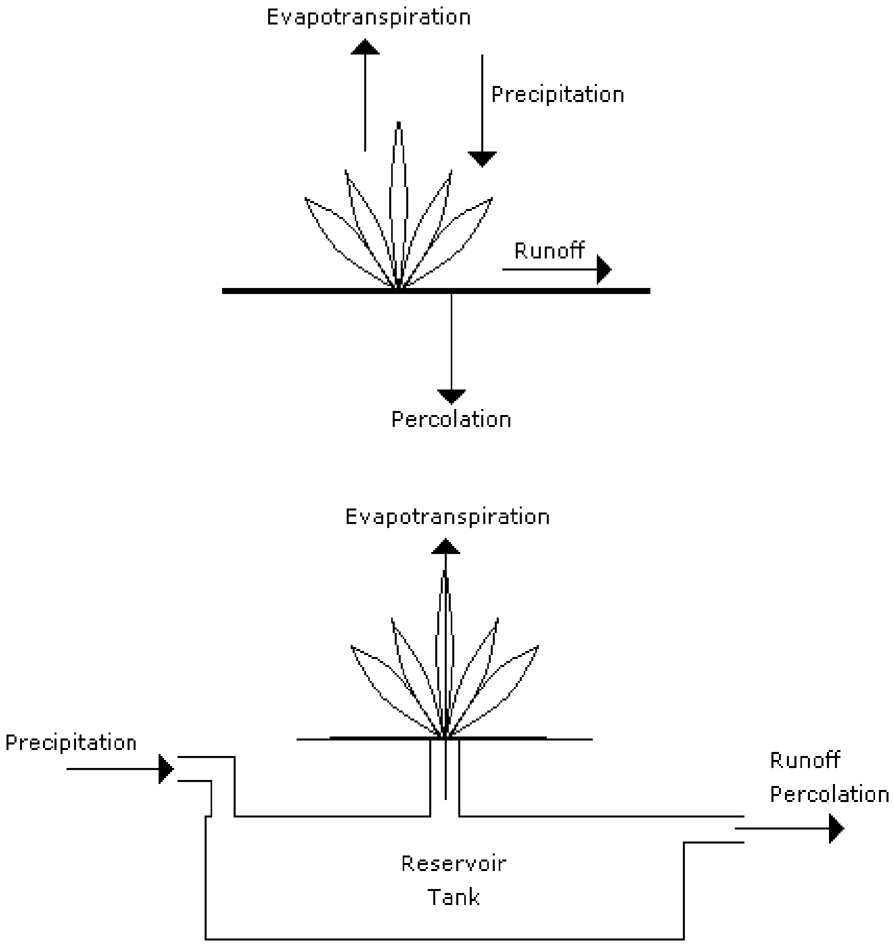


Figure 28: Schematic representation of the water balance around turf.

Step 1 – Soil Water Retention

Determination of the ability of a soil to hold water is important to understanding the size of the irrigation reservoir. This is dependent on two factors: (i) the soil type and (ii) the root zone depth. The volume of water that can be depleted before irrigation is required is given by the equation:

$$d_{SMC} = k_{SWR} \times d_{rz} \qquad \textbf{Eqn 3}$$

where d_{SMC} is soil's moisture capacity, k_{SWR} is the soil retention factor and d_{rz} is the depth of the root zone. Table 13 shows the soil retention factors for typical soil types for different turf growth rates. The turf growth rates are important as they are determined by the amount of available water in a turf. High growth will be seen where significant water is available. Consequently the reservoir size for these soils is smaller as irrigation should be triggered more regularly. Turfs that can have a lower growth rate have larger reservoirs as the soil moisture content can be more heavily depleted. This results in less frequent but larger irrigations.

The rootzone for a turf is affected by a number of properties including irrigation frequency, frequency of fertilizer application and mowing height. For this software the rootzone depth is assumed to be 40 cm.

Step 2 – Determining Evapotranspiration

Evapotranspiration (ET) can be calculated through two main of techniques: the pan evaporation model and the PenmanMonteith equation. The simplest of these is the pan evaporation model.

3.1.1 The Pan Evaporation Model

The ET in pan evaporation is defined by the equation:

$$d_{ET} = k_c d_{evap} \qquad \textbf{Eqn 4}$$

Where d_{ET} is the actual evapotranspiration, d_{evap} is the evaporation from a flat water surface (or water pan) and k_c is the crop factor for the turf.

EP evaporation data can be obtained from the Bureau of Meteorology. Within Melbourne there are three main sites measuring evaporation: Melbourne Airport, Melbourne Bureau of Meteorology Head Office and Latrobe University at Bundoora.

Table 13: Allowable soil moisture depletion (in mm.cm^{-1}) for different soil textures under different growth regimes. Adapted from [12] and after consultation with local municipal authorities

Soil Type	Growth Required		
	Strong	Average	Just Acceptable
Sand	0.5	0.6	0.6
Loamy Sand	0.7	0.8	0.9
Sandy Loam	1.1	1.2	1.3
Loam	1.7	1.8	2.0
Poor-Structured Clay	1.0	1.1	1.3
Good-Structured Clay	1.3	1.6	1.9

Table 14: Pan evaporation crop factors for warm- and cool-season turfs under different growth conditions. Adapted from [12] and after consultation with local municipal authorities.

Turf Type	Growth Required		
	Strong	Average	Just Acceptable
Warm-Season	0.5	0.45	0.25
Cool-Season	0.725	0.7	0.65

Crop factors are dependent on the turf type and the amount of growth required. The last of these is due to the fact that growth is dependent on water and greater growth will therefore use greater water. Table 14 shows the crop factors for warm- and cool-season turfs under different growth requirements. It is important that the growth selected at this point is the same as that selected for soil moisture as ET is also dependent on the amount of water available in the soil [14].

3.1.2 The Penman-Monteith Model

A possible alternative to the Pan evaporation model is the PenmanMonteith model. This model is somewhat more complicated and requires significantly more input information and processing, however all the required data is available through the Bureau of Meteorology. A trial run was performed using this method however significant overestimation was seen, as shown in Figure 29. This model therefore was not employed in the programme.

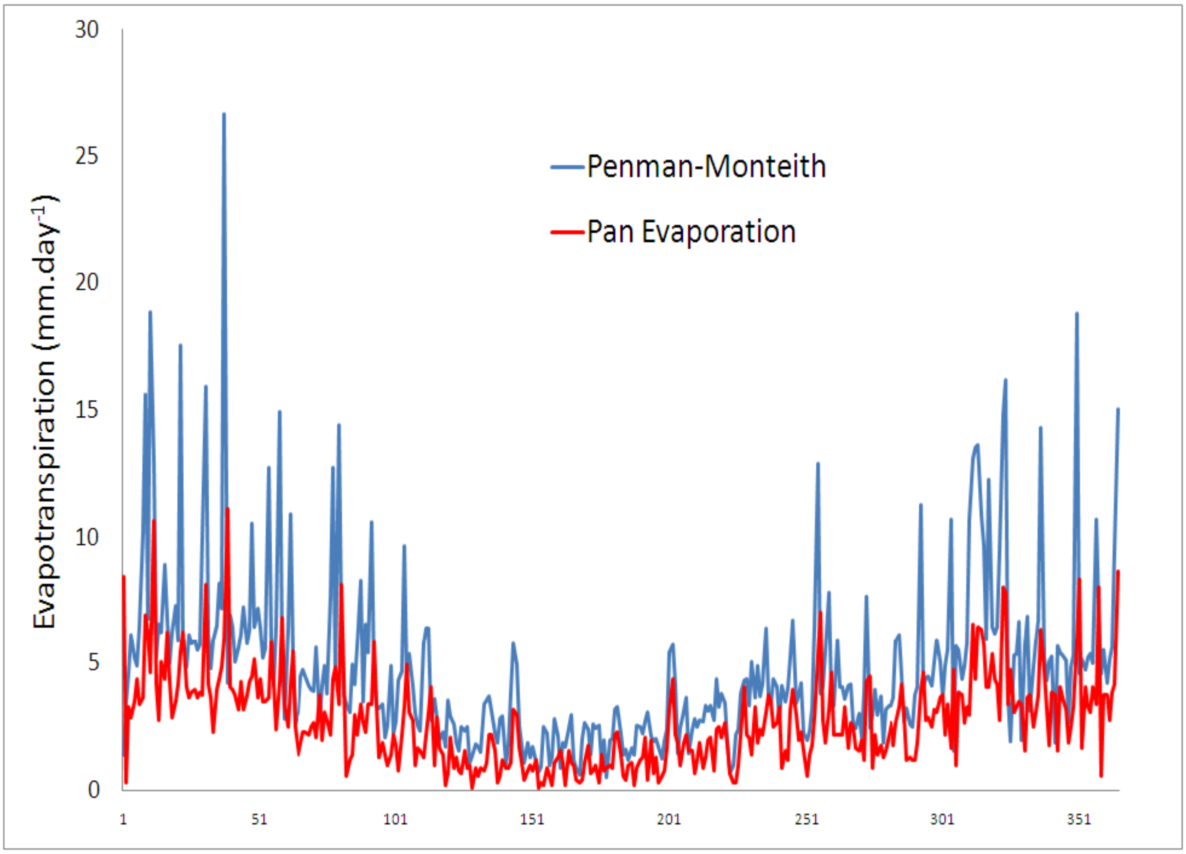


Figure 29: Comparison of evapotranspiration methods using the Pan evaporation and Penman-Monteith models.

After determining the evapotranspiration losses on a daily basis and the determining the maximum soil water storage and the trigger point for irrigation (based on the "size" of the soil reservoir), the only important information missing is the precipitation. This data is taken from the local weather stations throughout Melbourne and are listed in Section 2.2. In general the data was used directly from the Bureau of Meteorology's files; however there are occasionally gaps in this data. Where the gaps exceed one week these have been filled using data from the closest weather station.

To obtain the irrigation demand on a daily basis the following calculations are performed by the software:

$$d_{SM_{n+1}} = d_{SM_n} + d_{rain} - d_{ET_n} \qquad \textbf{Eqn 5}$$

Where $d_{SM_{n+1}}$ and d_{SM_n} is the soil moisture constant at day n+1 and n respectively, d_{rain} is the precipitation on day n and d_{ET_n} is the calculated evapotranspiration on day n.

$$if\ d_{SM_{n+1}} < 0, then\ d_{irr_n} = d_{SMC} - d_{SM_{n+1}}\ and\ d_{SM_{n+1}} = d_{SMC}$$

$$if\ d_{SM_{n+1}} > d_{SMC}, then\ d_{SM_{n+1}} = d_{SMC}$$

Where d_{irr_n} is the irrigation depth on day n in mm. The volume required for irrigation is then calculated by:

$$V_{irr_n} = d_{irr_n} \times A_{field} \times \varepsilon_{irr} \times 10 \qquad \textbf{Eqn 6}$$

Where V_{irr_n} is the irrigation volume required on day n, A_{field} is the area of the field and ε_{irr} is the irrigation efficiency that is assumed as 75%.

3.2 Water Supplied

The water supplied for irrigation is calculated in a specific order to ensure more sustainable options as well as simpler options are employed first. The order of calculation is:

- Rain Water
- Storm Water
- Grey Water
- Decentralized Recycled Water
- Centralized Recycled Water
- Ground Water
- Brackish Water
- Sea Water
- Custom Water
- Potable Water

The following sections detail the calculations of availability for each water source.

3.2.1 Rainwater

For rainwater collection the required information is:

- Rooftop area (A_{roof})
- Volume of rainwater tank/storage ($V_{raintank}$)
- Daily precipitation data (d_{rain})

There is also an option within the input to optimize the size of the tank. Where this is the case the target reliability (ρ_{aim}) is also required. Where optimization is not required the following calculations are performed.

- The tank is initially empty:

$$V_{rainstored_0} = 0$$

- The programme checks if there is sufficient water in the tank to meet the needs of irrigation:

$$if\ V_{rainstored_n} > V_{irr_n}\ then\ V_{rain_n} = V_{irr_n}$$

$$otherwise\ V_{rain_n} = V_{rainstored_n}$$

- The volume of water in the tank is then calculated:

$$V_{rainstored_{n+1}} = V_{rainstored_n} + \frac{d_{rain} \times A_{roof}}{1000} - V_{rain_n} \qquad \textbf{Eqn 7}$$

- The possibility of overflow is then checked:

$$If\ V_{rainstored_{n+1}} > V_{raintank}\ then\ V_{rainstored_{n+1}} = V_{raintank}$$

- The reliability of supply is also calculated using the equation:

$$\rho = \frac{\sum_n V_{rain_n}}{\sum_n V_{irr_n}} \qquad \textbf{Eqn 8}$$

Where optimization is required the previous calculations are performed for the first run, the reliability compared to the aim and a new rain tank volume determined for a new iteration. Here the conditions under which a new volume is determined are important:

- Initially a Boolean variable MRR (or variable that takes he value true or false) is developed and set to false. This Boolean is later used to indicated whether a maximum in reliability has been reached:
- The conditions are checked to see if a reduction in tank volume may be required.

$$If\ (MRR = true\ or\ \rho > \rho_{aim})\ and\ V_{raintank} > 10, then\ V_{raintank_{new}} = V_{raintank} - 10$$

$$If\ (MRR = true\ or\ \rho > \rho_{aim})\ and\ 1 < V_{raintank} \leq 10, then\ V_{raintank_{new}} = V_{raintank} - 1$$

$$If\ (MRR = true\ or\ \rho > \rho_{aim})\ and\ V_{raintank} \leq 1, then\ an\ error\ message\ is\ displayed$$

- The calculations detailed above are then rerun using $V_{raintank_{new}}$ instead of $V_{raintank}$
- The calculated reliabilities are then compared to determine how the calculations proceed:

$$If\ (\rho_{new} > \rho\ or\ \rho_{new} > \rho_{aim})\ then\ \left(V_{raintank} = V_{raintank_{new}}\ and\ \rho = \rho_{new}\right)\ iteration\ continues$$

$$Otherwise\ iteration\ is\ complete$$

If the above conditions were not met, then the programme will increase the size of the tank:

$$V_{raintank_{new}} = V_{raintank} + 10$$

- The calculation detailed above are then rerun using $V\_raintank_{new}$ instead of $V_{raintank}$
- If the new reliability is found to be less than or equal to the old reliability then the Boolean MRR (indicating the maximum reliability has been achieved) is set to true and iterations continue. Otherwise:

$$If\ (\rho_{new} > \rho\ and\ \rho_{new} < \rho_{aim})\ then\ \left(V_{raintank} = V_{raintank_{new}}\ and\ \rho = \rho_{new}\right)\ iteration\ continues$$

$$Otherwise\ V_{raintank} = V_{raintank_{new}}, \rho = \rho_{new} and\ iteration\ is\ complete$$

- When the iterations are complete the irrigation demand is adjusted to account for demand that was met:

$$V_{irr_n} = V_{irr_n} - V_{rain_n} \qquad \textbf{Eqn 9}$$

3.2.2 Stormwater

The stormwater calculations are somewhat the more complicated calculations in the software due to the different way in which water interacts with various surfaces in the catchment. There are a number of techniques to deal with this, however the approach outlined by Mitchell and coworkers [14] was simplified and adapted for use in the software due to the relative ease with which it can be implemented. Other software looks at the variation in flow rates over smaller time frames than a day, however they are generally used for sizing delivery and treatment systems and not for determining the volume of water made available and for this reason, they are not used here. The flow diagram for the water balance is shown in Figure 30.

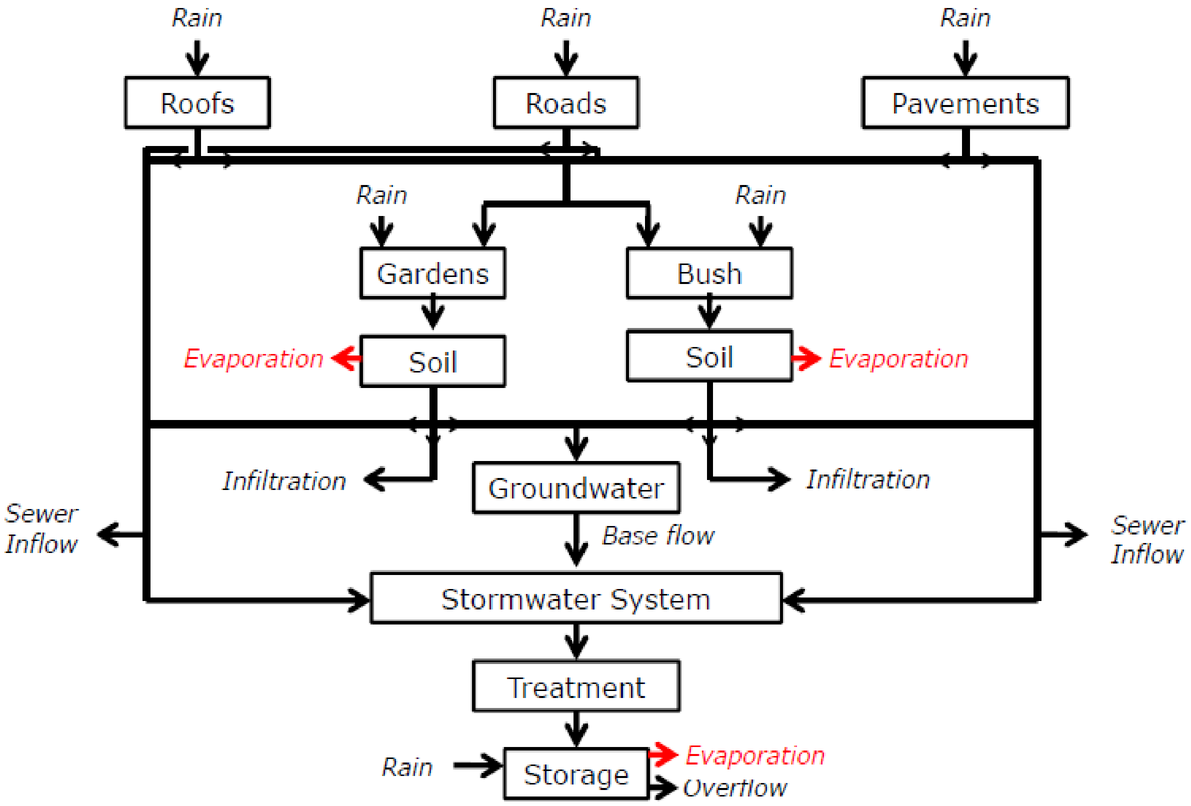


Figure 30: Flow diagram of water balance in stormwater model

The calculations are somewhat complicated and require a substantial amount of information. Initially the water that is soaks into and is "stored" in the pervious soils in gardens and bushland is calculated so that runoff from these surfaces can be estimated:

$$V_{lawnstore_{n+1}} = V_{lawnstore_n} + V_{lawn_{rain}} - V_{lawn_{evap}} + V_{lawn_{pervrunoff}} \qquad \textbf{Eqn 10}$$

Where:

$$V_{lawn_{rain}} = d_{rain} \times \frac{\%_{lawn}}{100} \times A_{catch} \times 10 \qquad \textbf{Eqn 11}$$

$$V_{lawn_{evap}} = \frac{V_{lawnstore_n} \times k_{c_{lawn}} \times d_{evap_n}}{d_{SMC_{lawn}}} \qquad \textbf{Eqn 12}$$

$$V_{lawn_{impervrunoff}} = \left(\left(\frac{1-\%_{roofconn}}{100}\right) \times \frac{\%_{roof}}{100} + \left(\frac{1-\%_{roadconn}}{100}\right) \times \frac{\%_{road}}{100} + \left(\frac{1-\%_{paveconn}}{100}\right) \times \frac{\%_{pave}}{100}\right) \times d_{rain_n} \times A_{catch} \times 10 \times \frac{\%_{lawn}}{\%_{lawn}+\%_{bush}} \qquad \textbf{Eqn 13}$$

The water in excess of root zone soil saturation can then be calculated:

$$if\ V_{lawnstore_{n+1}} > \left(d_{SMC_{lawn}} \times \frac{\%_{lawn}}{100} \times A_{catch} \times 10\right)$$

$$then\ V_{lawnexcess_n} = V_{lawnstore_{n+1}} - d_{SMC_{lawn}} \times \frac{\%_{lawn}}{100} \times A_{catch} \times 10$$

$$and\ V_{lawnstore_{n+1}} = d_{SMC_{lawn}} \times \frac{\%_{lawn}}{100} \times A_{catch} \times 10$$

$$otherwise\ V_{lawnexcess_n} = 0$$

Similar calculations are used for determining the potential for runoff from bushland:

$$V_{bushstore_{n+1}} = V_{bushstore_n} + V_{bush_{rain}} - V_{bush_{evap}} + V_{bush_{pervrunoff}} \qquad \textbf{Eqn 14}$$

Where:

$$V_{bush_{rain}} = d_{rain} \times \frac{\%_{bush}}{100} \times A_{catch} \times 10 \qquad \textbf{Eqn 15}$$

$$V_{bush_{evap}} = \frac{V_{bushstore_n} \times k_{c_{bush}} \times d_{evap_n}}{d_{SMC_{bush}}} \qquad \textbf{Eqn 16}$$

$$V_{bush_{impervrunoff}} = \left(\left(\frac{1-\%_{roofconn}}{100}\right) \times \frac{\%_{roof}}{100} + \left(\frac{1-\%_{roadconn}}{100}\right) \times \frac{\%_{road}}{100} + \left(\frac{1-\%_{paveconn}}{100}\right) \times \frac{\%_{pave}}{100}\right) \times d_{rain_n} \times A_{catch} \times 10 \times \frac{\%_{bush}}{\%_{lawn}+\%_{bush}} \qquad \textbf{Eqn 17}$$

The water in excess of root zone soil saturation can then be calculated:

$$if\ V_{bushstore_{n+1}} > \left(d_{SMC_{bush}} \times \frac{\%_{bush}}{100} \times A_{catch} \times 10\right)$$

$$then\ V_{bushexcess_n} = V_{bushstore_{n+1}} - d_{SMC_{bush}} \times \frac{\%_{bush}}{100} \times A_{catch} \times 10$$

$$and\ V_{bushstore_{n+1}} = d_{SMC_{bush}} \times \frac{\%_{bush}}{100} \times A_{catch} \times 10$$

$$Otherwise\ V_{bushexcess_n} = 0$$

The water balance around the groundwater aquifer is given by:

$$V_{aquifer_{n+1}} = \left(1 - k_{baseflow}\right) \times V_{aquifer_n} + k_{BFI} \times \left(V_{lawnexcess_n} + V_{bushexcess_n}\right) \qquad \textbf{Eqn 18}$$

It should be noted that no limits on the volume of the aquifer are used in this software and it is assumed to initially be empty. It is, for all intents and purposes, a water sink. The daily flow of water into a treatment process can then be calculated by:

$$Q_{stormtreat_n} = \left(1 - f_{sewerinflow}\right) \times \left(Q_{roofrun_n} + Q_{road_n} + Q_{pave_n} + Q_{lawn_n} + Q_{bush_n}\right) + Q_{baseflow_n} \qquad \textbf{Eqn 19}$$

Where:

$$Q_{roofrun_n} = d_{rain} \times \frac{\%_{roofconn}}{100} \times \frac{\%_{roof}}{100} \times A_{catch} \times 10 \qquad \textbf{Eqn 20}$$

$$Q_{roadrun_n} = d_{rain_n} \times \frac{\%_{roadconn}}{100} \times \frac{\%_{road}}{100} \times A_{catch} \times 10 \qquad \textbf{Eqn 21}$$

$$Q_{paverun_n} = d_{rain_n} \times \frac{\%_{paveconn}}{100} \times \frac{\%_{pave}}{100} \times A_{catch} \times 10 \qquad \textbf{Eqn 22}$$

$$Q_{lawn_n} = \left(1 - k_{II} - k_{BFI}\right) \times V_{lawnexcess_n} \qquad \textbf{Eqn 23}$$

$$Q_{bush_n} = \left(1 - k_{II} - k_{BFI}\right) \times V_{bushexcess_n} \qquad \textbf{Eqn 24}$$

$$Q_{baseflow_n} = k_{baseflow} \times V_{aquifer_n} \qquad \textbf{Eqn 25}$$

To determine the volume of water in the stormwater storage area, we must first determine how much water is used for irrigation:

$$if\ V_{stormstored_n} \geq V_{irr_n}\ then\ V_{storm_n} = V_{irr_n}$$

$$otherwise\ V_{storm_n} = V_{stormstored_n}$$

The water balance around the stormwater storage is then given by:

$$V_{stormstored_{n+1}} = V_{stormstored_n} + Q_{stormtreat_n} \times f_{stormtreat} - \frac{d_{evap_n} \times A_{exposed}}{1000} + \frac{d_{rain_n} \times A_{exposed}}{1000} - V_{storm_n} \qquad \textbf{Eqn 26}$$

$$If\ V_{stormstored_{n+1}} > V_{stormtank}\ then\ V_{stormover_n} = V_{stormstored_{n+1}} - V_{stormtank}$$

$$and\ V_{stormstored_n} = V_{stormtank}$$

$$If\ V_{stormstored_{n+1}} < 0\ then\ V_{stormstored_{n+1}} = 0$$

The irrigation demand is then adjusted:

$$V_{irr_n} = V_{irr_n} - V_{storm_n} \qquad \textbf{Eqn 27}$$

3.2.3 Decentralized Water Sources

The grey water and decentralized recycled water options are mathematically treated in very similar ways. The calculations for grey water are outlined first, followed by the important differences between this and the decentralized recycled water options.

3.2.3.1 Unlimited Supply

Where an unlimited supply of grey water was selected, the calculations are quite simple:

$$V_{grey_n} = V_{irr_n} \times \frac{\%greyshandy}{100} \qquad \textbf{Eqn 28}$$

The irrigation demand and potable water use can then be adjusted accordingly:

$$V_{irr_n} = V_{irr_n} - \frac{V_{grey_n}}{\left(\frac{\%greyshandy}{100}\right)} \qquad \textbf{Eqn 29}$$

$$V_{potable_n} = V_{potable_n} + V_{grey_n} \times \frac{\frac{100-\%greyshandy}{100}}{\frac{\%greyshandy}{100}} \qquad \textbf{Eqn 30}$$

3.2.3.2 Limited Supply, No Storage

Where a volume of grey water has been specified, the programme will allow full irrigation until the limit is reached. All irrigation beyond this point is unmet demand. The calculations are similar to those for unlimited supply, however, they include a check for the total volume utilized.

$$V_{grey_n} = V_{irr_n} \times \frac{\%greyshandy}{100} \qquad \textbf{Eqn 31}$$

At each iteration the total volume of greywater used is determined:

$$V_{grey_{total}} = \frac{\sum_n V_{grey_n}}{f_{greytreat}} \qquad \textbf{Eqn 32}$$

$$if\ V_{greytreat} > V_{grey_{max}}\ then\ V_{grey_n} = V_{grey_n} - \left(V_{grey_{total}} - V_{grey_{max}}\right) \qquad \textbf{Eqn 33}$$

Once the simulation is run, the irrigation demand and potable water use are adjusted as before.

3.2.3.3 Limited Supply, With Storage

This scenario is treated slightly differently from that above in that it assumes a constant, but limited supply of grey water is made available throughout the year. This is made available at the constant rate of:

$$Q_{greyin} = \frac{V_{grey_{max}} \times f_{greytreat}}{365 \times} \qquad \textbf{Eqn 34}$$

Initially the grey water storage tank is set to empty:

$$V_{greystored_0} = 0$$

Conditions are then checked to determine how irrigation demand is met:

$$if\ V_{greystored_n} < V_{irr_n} \times \frac{\%_{greyshandy}}{100}\ then\ V_{grey_n} = V_{greystored_n}$$

$$otherwise\ V_{greystored_n} = V_{irr_n} \times \frac{\%_{greyshandy}}{100}$$

A water balance is then performed around the tank:

$$V_{greystored_{n+1}} = V_{greystored_n} + Q_{greyin} - V_{grey_n}$$

$$if\ V_{greystored_{n+1}} > V_{greytank}\ then\ V_{greystored_{n+1}} = V_{greytank}$$

$$if\ V_{greystored_{n+1}} < 0\ then\ v_{greystored_{n+1}} = 0$$

Storage optimization can be performed using the iteration method described previously for rainwater.

After simulation the irrigation demand and potable water use can be adjusted as before.

3.2.3.4 Decentralized Catchment

Where a decentralized catchment has been specified a similar calculation to that about is performed. That is to say it is assumed that water from the catchment is provided at a constant rate throughout the year. However, the total volume that is provided needs to be estimated:

$$V_{grey_{max}} = \frac{n_{houses} \times n_{occupancy} \times V_{greyhouse} \times 0.46}{1000} \qquad \textbf{Eqn 35}$$

Where n_{houses} is the number of houses in the catchment, $n_{occupancy}$ is the average occupancy in the catchment, $V_{greyhouse}$ is the average water usage per person per day in the catchment and 0.46 is the fraction of residential water use that becomes wastewater suitable for grey water recycling.

This last factor assumes all wastewater except from the toilet and irrigation water is made available as greywater. The remainder of the calculations are performed in the same way as Section 3.2.3.3.

3.2.3.5 Catchment Optimization

Unlike storage optimization, catchment optimization is not based around the provided number, but instead starts with a small catchment that is increased throughout the iterations. This uses Eqn 35, but gives an initial value for n_{houses} as 10. The calculations are then performed as described in Section 3.2.3.3, with the exception that the volumetric reliability is also calculated according to Eqn 8. After this initial calculation the following logic is used for subsequent iterations:

$$If\ \rho_{grey} < \rho_{aim}\ and\ small\ step\ changes\ are\ not\ used\ then\ n_{houses} = n_{houses} + 10$$

$$If\ \rho_{grey} < \rho_{aim}\ and\ small\ step\ changes\ are\ used\ then\ n_{houses} = n_{houses} + 1$$

$V_{grey_{max}}$ is then calculated, the calculation in Section 3.2.3.3 reperformed and $\rho_{grey_{new}}$ is calculated.

$$if\ \rho_{grey_{new}} \leq\ \rho_{grey}\ and\ n_{houses} > 100\ then\ the\ iteration\ stops$$

$$otherise\ if\ \rho_{grey_{new}} \leq\ \rho_{grey} and\ small\ step\ changes\ are\ used\ then\ the\ iteration\ stops$$

$$otherwise\ if\ \rho_{grey_{new}} \leq\ \rho_{grey}\ and\ n_{houses} < 100$$

$$then\ small\ step\ changes\ will\ be\ used\ and\ iteration\ continues$$

$$otherwise\ n_{houses} = n_{houses_{new}}\ and\ \rho_{grey} =\ \rho_{grey_{new}}\ and\ iteration\ continues$$

3.2.3.6 Differences for Recycled Water

The main difference for decentralized recycled water calculations comes in calculations of the amount of water available from each house. The equation for this becomes:

$$V_{sewer_{max}} = \frac{n_{houses} \times n_{occupancy} \times V_{sewerhouse} \times 0.66}{1000} \qquad \textbf{Eqn 36}$$

Where 0.66 represents the proportion of water used in the house that becomes black water for recycling. This effectively excludes only irrigation water.

3.2.3.7 Local Catchment

For the local catchment, the greywater or sewage catchment is define by individual uses. For greywater the calculations performed are:

$$V_{grey_m} = (n_{visitors} \times 0.6 \times V_{handwash} + n_{showerusers} \times V_{shower} + V\_kitchen) \times \frac{52.25}{1000} \qquad \textbf{Eqn 37}$$

Where $n_{visitors}$ is the number of visitors to the field every week, 0.6 if a factor to determine the number of toilet visits based around the number of visitors, $V_{handwash}$ is the volume of water used per handwash, $n_{showerusers}$ is the number of people who use the showers each week, V_{shower} is the average volume of water used to shower and $V_{kitchen}$ is the weekly volume of water used by the kitchen. All volumes are assumed to be in litres.

For sewage the calculations are:

$$V_{sewer_m} = \left(n_{visitors} \times 0.6 \times \left(V_{handwash} + V_{flush}\right) + n_{showerusers} \times V_{shower} + V_{kitchen}\right) \times \frac{52.25}{1000}$$

Eqn 38

Where V_{flush} is the average water used per toilet flush.

The overall calculations are then made as in Section 3.2.3.3.

3.2.4 Other Water Sources

All other water sources are calculated in a similar way and can be related to the greywater calculations above. The three different scenarios are described below.

3.2.4.1 Unlimited

For unlimited supplies, the equations are quite simple and mimic those used in Section 3.2.3.1:

$$V_{y_n} = V_{irr_n} \times \frac{\%_{yshandy}}{100}$$

Eqn 39

Where V_{y_n} is the volume of water from source y used in day n, V_{irr_n} is the irrigation demand on day n and $\%_{yshandy}$ is the percentage of water from source y shandied with potable water for irrigation.

The irrigation demand and potable water use are then adjusted accordingly:

$$V_{irr_n} = V_{irr_n} - \frac{V_{y_n}}{\left(\frac{\%_{yshandy}}{100}\right)}$$

Eqn 40

$$V_{potable_n} = V_{potable_n} + V_{y_n} \times \frac{\frac{100-\%_{yshandy}}{100}}{\frac{\%_{yshandy}}{100}}$$

Eqn 41

3.2.4.2 Limited Supply, No Storage

This is effectively the same as for decentralized water sources in Section 3.2.3.2. Where a volume of water has been specified, the programme will allow full irrigation until the limit is reached. All irrigation beyond this point is unmet demand. The calculations are similar to those for unlimited supply, however, they include a check for the total volume utilized.

$$V_{y_n} = V_{irr_n} \times \frac{\%_{yshandy}}{100}$$

Eqn 42

At each iteration the total volume of water used is determined:

$$V_{y_{total}} = \frac{\sum_n V_{y_n}}{f_{ytreat}}$$

Eqn 43

$$if\ V_{y_{total}} > V_{y_{max}}\ then\ V_{y_n} = V_{y_n} - \left(V_{y_{total}} - V_{y_{max}}\right)$$

Eqn 44

Once the simulation is run, the irrigation demand and potable water use are adjusted as before.

3.2.4.3 Limited Supply, With Storage

This is effectively the same as for decentralized water sources in Section 3.2.3.3. It treated slightly differently from that above in that it assumes a constant, but limited supply of water is made available throughout the year. This is made available at the constant rate of:

$$Q_{yin} = \frac{V_{y_m} \times f_{ytreat}}{365} \qquad \textbf{Eqn 45}$$

Initially the water storage tank is set to empty:

$$V_{ystored_0} = 0$$

Conditions are then checked to determine how irrigation demand is met:

$$if\ V_{ystored_n} < V_{irr_n} \times \frac{\%_{yshandy}}{100}\ then\ V_{y_n} = V_{ystored_n}$$

$$otherwise\ V_{ystored_n} = V_{irr_n} \times \frac{\%_{yshandy}}{100}$$

A water balance is then performed around the tank:

$$V_{ystored_{n+1}} = V_{ystored_n} + Q_{yin} - V_{y_n}$$

$$if\ V_{ystored_{n+1}} > V_{ytank}\ then\ V_{ystored_{n+1}} = V_{ytank}$$

$$if\ V_{ystored_{n+1}} < 0\ then\ V_{ystored_{n+1}} = 0$$

Storage optimization can be performed using the iteration method described previously for rainwater (Section 3.2.1).

After simulation the irrigation demand and potable water can be adjusted as before.

3.2.5 Water Losses During Treatment

Water losses for a particular treatment train can be calculated from the product of the individual processes using the equation:

$$f_{treatment} = \prod_y f_y \qquad \textbf{Eqn 46}$$

Where y represents the individual treatment processes to be used. Table 15 show the water reduction rations (f_y) of treatment processes used by the software.

Table 15: Water reduction ratios for various treatment processes

Treatment	f_y	Reference
Activated Sludge Treatment	0.97	
Biological Nutrient Removal	0.97	
Disinfection	1	
Flocculation	0.97	[24]
Granular Activated Carbon	0.97	[24]
Grit Removal	0.99	
Microfiltration	0.85	[24]
Rain Garden	0.85	
Rapid Sand Filtration	0.97	[24]
Reverse Osmosis – Seawater	0.2	[25]
Reverse Osmosis – Brackish Water	0.75	[26,27]
Screening	1	
Sedimentation	0.97	[24]
Wetlands	0.85	

3.3 Nutrient Demand

3.3.1 Nitrogen, Phosphorus and Potassium Demand

Claims made by Beard [28] suggest that turf fertilizer requirements can be met simply through the application of clippings to a surface. If the question “Are clippings removed?” in the Sportsground Details Window (see Section 2.2) is answered “no” it is assumed no further fertilization is required. Otherwise the mass of nutrients removed needs to be replaced. This was estimated as 24, 4.5 and 22.5 $g.m^{-2}.y^{-1}$ for N, P and K respectively [28]. These values may be somewhat high however and will need to be assessed during the trial to ensure accuracy.

3.3.2 Calcium Demand

Calcium demand was determined based around the sodium adsorption ratio and the potential effects of salinity on a soil. For this the guidelines proposed by Harivandi [29] were used. These are shown in Table 16. Clay soils were treated as particularly sensitive to sodium concentrations while sandy soils were considered somewhat tolerant.

Table 16: Guidelines for SAR and conductivity of irrigation waters. Adapted from [29]

	Degree of problem		
	Negligible	Slight to Moderate	Severe
If SAR = 0 to 3 and EC	> 0.7	0.7 - 0.2	< 0.2
If SAR = 3 to 6 and EC	> 1.2	1.2 - 0.3	< 0.3
If SAR = 6 to 9 and EC	> 1.9	1.9 - 0.5	< 0.5
If SAR = 12 to 20 and EC	> 2.9	2.9 - 1.3	< 1.3
If SAR = 20 to 40 and EC	> 5.0	5.0 - 2.9	< 2.9

On each day's data the following calculations were performed:

$$if\ c_{Ca_{irr}} \neq 0\ and\ c_{Mg_{irr}} \neq 0\ then$$

$$SAR = \frac{\frac{c_{Na_{irr}}}{23}}{\sqrt{\frac{\frac{c_{Ca_{irr}}}{20}+\frac{c_{Mg_{irr}}}{12.2}}{2}}}$$ **Eqn 47**

$$otherwise\ SAR = 0\ and\ c_{Ca_{req}} = 0$$

For clay soils:

$$if\ SAR \leq 3\ then\ c_{Ca_{req}} = 0$$

$$if\ 0.7 < c_{EC_{irr}} \leq 1.2\ then\ c_{Ca_{req}} = 0.0084 \times c_{Na_{irr}}{}^{2} - 1.639 \times c_{Mg_{irr}} - c_{Ca_{irr}}$$

$$\begin{aligned} if\ 1.2 < c_{EC_{irr}} \leq 1.9\ and\ SAR \leq 6, then\ c_{Ca_{req}} \\ = 0.0021 \times c_{Na_{irr}}{}^{2} - 1.639 \times C_{Mg_{irr}} - c_{Ca_{irr}} \end{aligned}$$

$$if\ 1.9 < c_{EC_{irr}}\ and\ SAR \leq 9, then\ c_{Ca_{req}} = 0.00093 \times c_{Na_{irr}}{}^{2} - 1.639 \times c_{Mg_{irr}} - c_{Ca_{irr}}$$

For all other soils:

$$if\ SAR \leq 3\ then\ c_{Ca_{req}} = 0$$

$$if\ 0.2 < c_{EC_{irr}} \leq 0.3\ then\ c_{Ca_{req}} = 0.0084 \times c_{Na_{irr}}{}^{2} - 1.639 \times c_{Mg_{irr}} - c_{Ca_{irr}}$$

$$\begin{aligned} if\ 0.3 < c_{EC_{irr}} \leq 0.5\ and\ SAR \leq 6, then\ c_{Ca_{req}} \\ = 0.0021 \times c_{Na_{irr}}{}^{2} - 1.639 \times C_{Mg_{irr}} - c_{Ca_{irr}} \end{aligned}$$

$$if\ 0.5 < c_{EC_{irr}}\ and\ SAR \leq 9, then\ c_{Ca_{req}} = 0.00093 \times c_{Na_{irr}}{}^{2} - 1.639 \times c_{Mg_{irr}} - c_{Ca_{irr}}$$

To determine the mass of calcium required over the period of study the sum of all calcium requirements over the time period is taken. The mass can then be calculated through the equation:

$$m_{Ca_{req}} = c_{Ca_{req}} \times \frac{V_{irr_{total}}}{1000}$$ **Eqn 48**

3.4 Nutrients Supplied

3.4.1 Stormwater

The final concentrations of species in stormwater vary depending on the contribution from the various sources. As pervious sources can contribute variable amounts of water depending on the level of moisture already in the soil and the percentage lost to percolation through to groundwater, changes in the storage concentrations must be calculated on a daily basis. Though there is significant variation in the quality of water from various sources in the literature and there are a number of known factors that cause this variation, for the sake of simplicity an average quality was used to determine the concentration of important species in storm runoff from various surfaces. The following generalised equations describe how this was performed:

$$if\ V_{stormstored_n} = 0\ then$$

$$m_{x_{n+1}} = m_{x_n} + \left(c_{x_{roof}} \times V_{roofrun_n} + C_{x_{road}} \times V_{roadrun_n} + c_{x_{pave}} \times V_{paverun_n} + c_{x_{lawn}} \times V_{lawnrun_n} + c_{x_{bush}} \times V_{bushrun_n} + c_{x_{base}} \times V_{base_n} + c_{x_{rain}} \times \frac{d_{rain_n}}{1000} \times A_{exposed}\right) \times f_{x_{stormtreat}}$$

Eqn 49

$$otherwise$$

$$m_{x_{n+1}} = m_{x_n} + \left(c_{x_{roof}} \times V_{roofrun_n} + C_{x_{road}} \times V_{roadrun_n} + c_{x_{pave}} \times V_{paverun_n} + c_{x_{lawn}} \times V_{lawnrun_n} + c_{x_{bush}} \times V_{bushrun_n} + c_{x_{base}} \times V_{base_n} + c_{x_{rain}} \times \frac{d_{rain_n}}{1000} \times A_{exposed}\right) \times f_{x_{stormtreat}} - \left(V_{storm_n} + V_{stormover_n}\right) \times \frac{m_{x_n}}{V_{stormstored_n}}$$

Eqn 50

The main reason for the difference in the calculations is the potential for a zero denominator in the final term of the second equation. In general if there is no water in the storage, then there is no water available for irrigation where it is required and no possibility of overflow. If rain does fall and the storage starts to fill then it is unlikely irrigation water would be required and a very significant rainfall event would be required to fill the storage.

The average concentrations used are shown in Table 17.

Table 17: The average concentration of contaminants in stormwater runoff from different surfaces. Adapted from [5, 30-40].

Parameter	Source						
	Roof	Road	Pavement	Lawn	Bush	Baseflow	Rain
TN (ppm)	5.62	2.1	2.1	6.77	0.83	3	0.45
TP (ppm)	0.21	0.74	0.93	0.08	0.076	0.3	0.08
EC (mS.cm^{-1})	0.0975	0.1875	0.2025	0.3075	0.036	0.6	0.0292
Na (ppm)	43.4	43.6	5.2	60.4	6.04	32	0.98
K (ppm)	10.1	1.55	1.55	18	1.8	6.8	0.079
Mg (ppm)	7.32	2.07	1.5	7.2	0.72	24.2	0.13
Ca (ppm)	5.65	31.3	22.2	10.2	1.02	107	0.17

Table 18: The average concentration of contaminants in various domestic wastewater sources

Parameter	Source			
	Handwash	Shower	Kitchen	Toilet
TN (ppm)	8.77	8.77	57	220
TP (ppm)	0.42	0.42	71	40
TDS (ppm)	89.4	89.4	315	139
Na (ppm)	18.2	18.2	100	100
K (ppm)	3.18	3.18	39.3	82
Mg (ppm)	1.84	1.84	5	0.9
Ca (ppm)	7.23	7.23	22	1.5

3.4.2 Local Water Sources

For local water sources the average concentration is assumed to be constant with respect to time. The calculation for grey water are given by:

$$c_x = \frac{c_{x_{handwash}} \times V_{handwash} \times 0.6 \times n_{visitors} + c_{x_{shower}} \times V_{shower} \times n_{showerusers} + c_{x_{kitchen}} \times V_{kitchen}}{V_{grey_{max}}}$$

Eqn 51

While those for blackwater are given as:

$$c_x = \frac{\left(c_{x_{handwash}} \times V_{handwash} + c_{x_{toilet}} \times V_{flush}\right) \times 0.6 \times n_{visitors} + c_{x_{shower}} \times V_{shower} \times n_{showerusers} + c_{x_{kitchen}} \times V_{kitchen}}{V_{grey_{max}}}$$

Eqn 52

The various concentrations are shown in Table 18.

3.4.3 Other Sources

Most other water sources have defined water qualities during the user input stage and therefore do not need individual calculation the exception to this is the decentralized systems in grey water and decentralized sewage treatment. In these cases the volume of water is already known and average concentrations of the important species are assumed. These values are shown in Table 19.

All water sources can have reductions in these concentrations however, based on any treatment that the water may undergo before being used in irrigation. This is accounted for using the treatment reduction factor, $f_{x_{treatment}}$:

$$c_x = c_{x_{in}} \times f_{x_{treatment}} \qquad \text{Eqn 53}$$

Table 19: The average concentration of contaminants in raw grey water and raw sewage adapted from [15] and [21]

Parameter	**Source**	
	Raw Grey Water	**Raw Sewage**
TN (ppm)	12.5	57
TP (ppm)	8	7.3
TDS (ppm)	350	375
Na (ppm)	70	87.3
K (ppm)	15	16.8
Ca (ppm)	15	9.26
Mg (ppm)	30	4.93

3.4.4 Treatment Reductions

Treatment processes will reduce the concentrations of all of the species studied by the software. To determine how much of a reduction is achieved the following equation is employed:

$$f_{x_{treatment}} = \prod_y f_y \qquad \text{Eqn 54}$$

Where y represents the individual treatment processes. The factors for wetlands and rain gardens are dependent on the treatment area as a fraction of the impervious area of the catchment. As such these two treatments get treated separately. The factors for each of the individual treatment processes may be found in Table 20, while those of rain gardens and wetlands are given in Tables 21 and 22 respectively.

Table 20: Nutrient reduction factors for various processes

Process	f_{x_y}							References
	Na	Ca	K	Mg	TN	TP	TDS	
Activated Sludge	1	1	1	1	0.7	1	1	
Biological Nutrient Removal	1	1	1	1	0.1	0.3	1	
Disinfection	1	1	1	1	1	1	1	
Flocculation	1	1	1	1	0.85	0.85	1	
Granular Activated Carbon	1	1	1	1	0.95	1	1	
Grit Removal	1	1	1	1	1	1	1	
Microfiltration	1	0.90125	1	0.93	0.9	1	1	[26]
Rapid Sand Filtration	1	1	1	1	0.9055	0.56	1	
Reverse Osmosis – Seawater	0.015	0.005	0.015	0.005	0.015	0.005	0.015	[25, 41-43]
Reverse Osmosis – Brackish Water	0.1	0.05	0.1	0.05	0.1	0.01	0.1	[26, 44]
Screening	1	1	1	1	1	1	1	
Sedimentation	1	1	1	1	1	0.85	1	
Wetlands – Greywater	1	1	1	1	0.68	0.57	1	[45-49]

Table 21: Nutrient reduction factors for rain gardens of various sizes

Treatment area as % of impervious catchment area	f_{x_y}	
	TN	**TP**
0.5	0.74	0.6
1	0.64	0.25
1.5	0.59	0.19
2	0.56	0.16

Table 22: Nutrient reduction factors for wetlands of various sizes

Treatment area as % of impervious catchment area	f_{x_y}	
	TN	**TP**
1	0.71	0.55
2	0.59	0.39
3	0.52	0.32
4	0.47	0.27
5	0.44	0.25

3.5 Costing

Costing is determined for both capital costs and operation costs. In general previously unpublished data from the CSIRO is utilized to estimate costs based on cost curves.

3.5.1 Capital

Capital costs (in AU$k) are determined using the following equation:

$$\$_{cap_{treatment}} = \left(k_{cap_A} \times Q_{max}^2 + k_{cap_B} \times Q_{max} + k_{cap_C}\right) \times \frac{541.8}{390.6} \qquad \text{Eqn 55}$$

where, k_{cap_A}, k_{cap_b} and k_{cap_C} are empirical costing factors, Q_{max} is the maximum daily flow rate and the ratio represent the conversion from 1999 prices to March 2010 using the Chemical Plant Index [50, 51]. The costing factors are estimate based in individual units that are summed in treatment trains. The factors for the treatment trains used in this project are shown in Table 23. The estimate is performed by determining the total capital costs for the individual unit processes and then fitting a curve to the results.

Table 23: Capital cost factors for various treatment trains.

Water Source	Treatment Train	A Factor	B Factor	C Factor
Sea Water/ Brackish Water	Screening/MF/RO	-0.0002	1.5287	2.0428
Sea Water	Screening/MF/RO/RO	-0.0002	2.4682	-1.5515
Brackish Water	Screening/Rapid Sand Filtration	-0.0001	2.022	6.2688
Recycled Water	MF/RO	-0.00008	1.4199	-3.1206
Ground Water	Aeration/Rapid Sand Filtration	9x10^{-6}	0.0934	1.1054
Ground Water	Aeration/MF	-0.00004	0.4705	0.4736
Ground Water	Aeration/MF/RO	-0.00008	1.4199	-3.1206
Ground Water	Aeration/Rapid Sand Filtration/GAC/RO	-0.000002	1.3434	-0.1661
Ground Water	Aeration/MF/IX	0.0002	0.7599	31.908
Ground Water	Aeration/Rapid Sand Filtration/IX	0.0002	0.3828	32.54
Grey Water	Wetlands	0	0.465	0
Grey Water	Wetlands/Disinfection	-0.00005	0.35	2.5602
Grey Water	Screening/Grit Removal/Sedimentation/Activated Sludge/Disinfection	-0.0006	2.0832	93.693
Grey Water	Screening/Grit Removal/Sedimentation/Activated Sludge/Disinfection	-0.0006	2.0832	93.693
Storm Water	Sedimentation/Disinfection	-0.0001	0.3326	23.088
Storm Water	Screening/Microfiltration/Disinfection	-0.0003	0.5248	29.357
Decentralized Treatment	Biological Nutrient Removal/Rapid Sand Filtration/GAC/Disinfection	-0.0018	6.0385	67.417
Decentralized Treatment	Screening/Grit Removal/Flocculation/Activated Sludge/Rapid Sand Filtration/GAC/Disinfection	-0.0005	2.4772	97.121
Decentralized Treatment	Screening/Grit Removal/Flocculation/Activated Sludge/Disinfection	-0.0006	2.0832	93.693
Decentralized Treatment	Biological Nutrient Removal/Rapid Sand Filtration/GAC/MF/RO/Disinfection	-0.0019	7.4584	64.197
Decentralized Treatment	Screening/Grit Removal/Flocculation/Activated Sludge/Rapid Sand Filtration/GAC/MR/RO/Disinfection	-0.0006	3.8971	94.001
Decentralized Treatment	Screening/Grit Removal/Flocculation/Activated Sludge/MF/RO/Disinfection	-0.0007	3.5031	90.372

There are three exceptions to these cost estimates: wetlands and rain gardens for stormwater treatment and storage tanks.

For wetlands and rain gardens, the area of the natural treatment system is used. The equation instead becomes:

$$\$_{cap_{treatment}} = k_{cap} \times A_{treatment}$$

Eqn 56

Where k_{cap} is 0.0775 for wetlands and 0.25 for rain gardens with an area less than 100m^2 and 0.137 for rain gardens with an area greater than 100m^2.

The cost equation for tanks takes the form:

$$\$_{tank} = \frac{k_{tank_A} \times V_{tank}^{k_{tank_B}} \times \frac{541.8}{389.5}}{0.88 \times 1000}$$

Eqn 57

Where V_{tank} is the volume of the storage tank, k_{tank_A} and k_{tank_B} are costing factors specifically for tanks and are equal to 2300 and 0.55 respectively in the current software. The ratio at the end of the numerator converts 1998 prices to March 2010 [51, 52], while the conversion factor in the denominator converts from $US to $AUS. The costs for tanks can be quite high due to the materials of construction, there size and installation. It can really only be a guideline and for high reliability systems, a tank is probably not suitable. Aquifer recharge or open storage would be more appropriate options to pursue.

3.5.2 Operational

With the exception of wetlands and rain gardens, operational costs are calculated using the equation:

$$\$_{op_{treatment}} = \left(k_{op_A} \times Q_{max}^{k_{op_B}} \times \left(\frac{V_{total}}{f_{treat} \times \frac{n_{days}}{365}} \right) \right) \times \frac{541.8}{390.6}$$

Eqn 58

Where $\$_{op_{treatment}}$ is given in AU$k, k_{op_A} and k_{op_B} are the operational cost factors, V_{total} is the total water used and n_{days} is the total number of days used in the simulation. The cost factors are determined in much the same way as for capital costs using individual unit processes. A list of the operational cost factors for treatment trains is shown in Table 24.

As with capital costs, the operational costs for rain gardens and wetlands treatment systems are based on area:

$$\$_{op_{treatment}} = k_{op} \times A_{treatment}$$

Eqn 59

Where k_{op} is 0.00155 for wetlands, 0.0125 for rain gardens with and area less than 100 m^2 and 0.00685 for rain gardens with an area greater than 100 m^2.

The area for wetlands treatment is calculated in two different ways. For stormwater treatment the size is specified by the user as a function of the impervious catchment area:

$$A_{treatment} = \frac{\%treatment_{imperv}}{100} \times \left(\frac{\%_{road} \times \%_{roadconn} + \%_{roof} \times \%_{roofconn} + \%_{pave} \times \%_{paveconn}}{10000}\right) \times A_{catch} \times 10000 \quad \textbf{Eqn 60}$$

For greywater treatment the equations are based around the assumption that a 72 hour residence time is used and the wetlands has an average depth of 0.5 m. This means the equation is:

$$A_{treatment} = 6 \times Q_{max} \quad \textbf{Eqn 61}$$

Where Q_{max} is the flowrate of untreated greywater.

In addition to the treatment costs, there are also additional costs incurred for purchased waters, these are the potable and centralized recycled waters. The costs for these are simply added to the operational costs of any treatment:

$$\$_{operational} = \$_{op_{treatment}} + \$_{water} \times V_{waterused} \quad \textbf{Eqn 62}$$

Table 24: Operational cost factors for various treatment trains.

Water Source	Treatment Train	A Factor	B Factor
Sea Water/ Brackish Water	Screening/MF/RO	3.3935	-0.139
Sea Water	Screening/MF/RO/RO	4.2996	-0.093
Brackish Water	Screening/Rapid Sand Filtration	0.6292	-0.729
Recycled Water	MF/RO	1.5	0
Ground Water	Aeration/Rapid Sand Filtration	0.0425	$9\text{x}10^{-6}$
Ground Water	Aeration/MF	0.5	0
Ground Water	Aeration/MF/RO	1.5	0
Ground Water	Aeration/Rapid Sand Filtration/GAC/RO	1.9917	-0.075
Ground Water	Aeration/MF/IX	1.1877	-0.147
Ground Water	Aeration/Rapid Sand Filtration/IX	1.8619	-0.45
Grey Water	Wetlands	0.0093	0
Grey Water	Wetlands/Disinfection	0.847	-0.3296
Grey Water	Screening/Grit Removal/Sedimentation/Activated Sludge/Disinfection	26.391	-0.733
Grey Water	Screening/Grit Removal/Sedimentation/Activated Sludge/Disinfection	19.248	-0.692
Storm Water	Sedimentation/Disinfection	5.7779	-0.692
Storm Water	Screening/Microfiltration/Disinfection	3.6813	-0.312
Decentralized Treatment	Biological Nutrient Removal/Rapid Sand Filtration/GAC/Disinfection	4.1477	-0.272
Decentralized Treatment	Screening/Grit Removal/Flocculation/Activated Sludge/Rapid Sand Filtration/GAC/Disinfection	13.935	-0.528
Decentralized Treatment	Screening/Grit Removal/Flocculation/Activated Sludge/Disinfection	19.248	-0.692
Decentralized Treatment	Biological Nutrient Removal/Rapid Sand Filtration/GAC/MF/RO/Disinfection	5.0622	-0.134
Decentralized Treatment	Screening/Grit Removal/Flocculation/Activated Sludge/Rapid Sand Filtration/GAC/MR/RO/Disinfection	10.637	-0.284
Decentralized Treatment	Screening/Grit Removal/Flocculation/Activated Sludge/MF/RO/Disinfection	9.7714	-0.297

3.6 Greenhouse Gas Emissions

Two main sources of greenhouse gas emission were considered: direct release of the gases N_2O, CO_2 and CH_4 from wastewater treatment processes (more specifically biological treatment in activated sludge plants or in wetlands) and through electricity usage. While there are other indirect sources such as in the production of potable water and various recycled water, it was ultimately decided to exclude these as any future tax or trading scheme would focus on direct emissions with other emissions reflected in the cost of water and other materials.

For wetlands and rain gardens the greenhouse gas emissions can be calculated using:

$$m_{GHG_{wet}} = A_{treatment} \times k_{wet_{GHG}} \qquad \textbf{Eqn 63}$$

Where $m_{GHG_{wet}}$ is the CO_2 mass equivalent of greenhouse gases emitted, $A_{treatment}$ is the area of the natural treatment system in m^2 and $k_{wet_{GHG}}$ is the greenhouse gas factor for wetlands and is estimated as 13.63 in the software [46, 47, 53, 54]. There is insufficient data to determine a factor for rain gardens, so these currently use the wetlands value, despite this likely being an overestimate.

Other treatment emissions are considered to come primarily from biological nutrient removal and activated sludge treatment. They can be estimated using the equation:

$$m_{GHG_{treat}} = k_{treat_{GHG}} \times \frac{\frac{V_{total}}{f_{treat} \times 1000}}{\frac{n_{days}}{365}} \qquad \textbf{Eqn 64}$$

Where V_{total} is the total water treatment in the process, f_{treat} is the water treatment loss factor, n_{days} is the number of days in the simulation and $k_{treat_{GHG}}$ is the greenhouse gas factor for the individual treatment option. For activated sludge this is 46.3 [55] while for biological nutrient removal it is 81.5.

The final component in greenhouse gas determinations is the indirect generation for electricity usage. It is estimated using the equation:

$$m_{GHG_{elec}} = E_{process} \times k_{elec_{GHG}} \qquad \textbf{Eqn 65}$$

Where $E_{process}$ is the electricity consumed during treatment and $k_{elec_{GHG}}$ is the mass equivalent of CO_2 generated per kWh production of electricity in Victoria. The last of these takes the value 1.22 [56]. The electricity used during treatment is found by summing the individual unit processes. Table 25 gives the electricity consumption for individual processes used in this software.

Finally, the total greenhouse gas emissions are given by:

$$m_{GHG_{total}} = m_{GHG_{wet}} + m_{GHG_{treat}} + m_{GHG_{elec}} \qquad \textbf{Eqn 66}$$

Table 25: Electricity consumption for various unit processes

Unit Process	Energy Consumption (kWh/kL treated)	References
Activated Sludge Treatment	0.287	[55, 57-60]
Biological Nutrient Removal	0.324	[59]
Disinfection (Chlorination)	8.5×10^{-4}	[58]
Flocculation	0.071	[24, 61]
Granular Activated Carbon	0.1	[24, 62]
Grit Removal	0.014	
Microfiltration	0.19	[58, 60, 63]
Nanofiltration	0.553	[62]
Rain Garden	0.014	
Rapid Sand Filtration	0.032	[24, 61]
Reverse Osmosis (Seawater)	4.5	[24, 61, 64-66]
Reverse Osmosis (Brackish Water)	1.7	[24,62]
Screening	0.014	
Sedimentation	0.07	
Wetlands	0.014	[62]

4 Overview of the Programme – Outputs

The software has been programmed to interface with Microsoft Excel in term of outputs. Each simulation is designed to generate two filled spreadsheets and a number of charts. These are explained in more detail in the following sections.

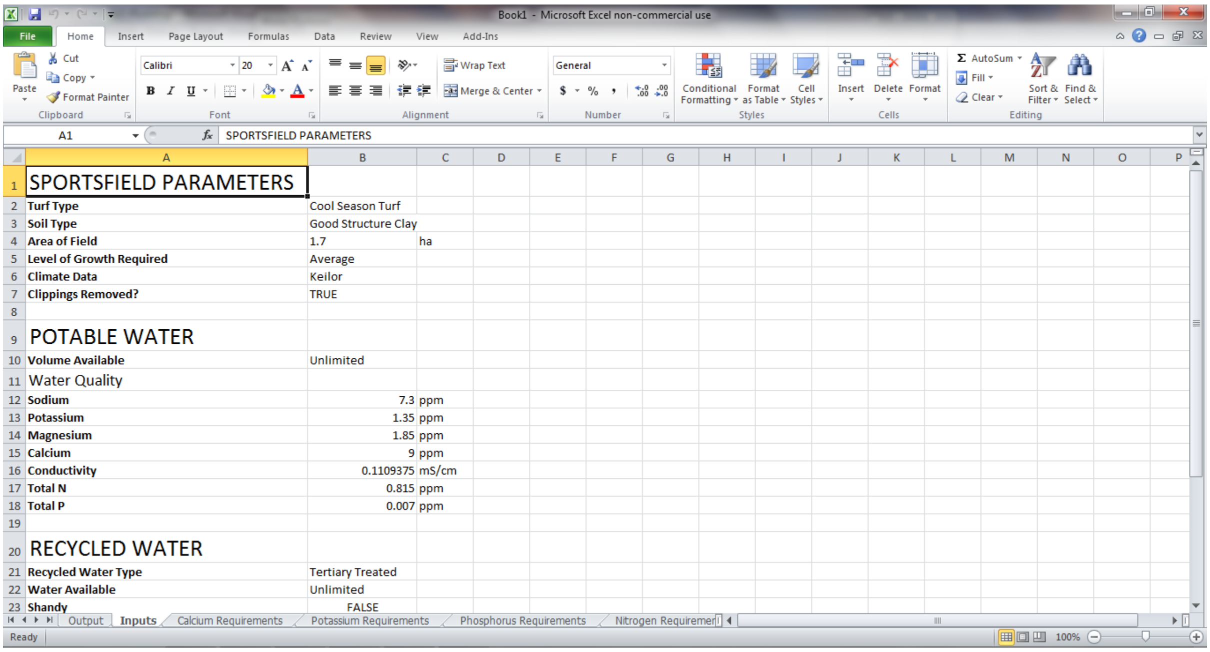
4.1 Input Summary

The summary of inputs may be found in the tab marked “Inputs” and an example is shown in Figure 31. This spreadsheet contains all data inputted into the system, in this case the sportsfield parameters and details on the potable water and recycled water available.

4.2 Results Summary

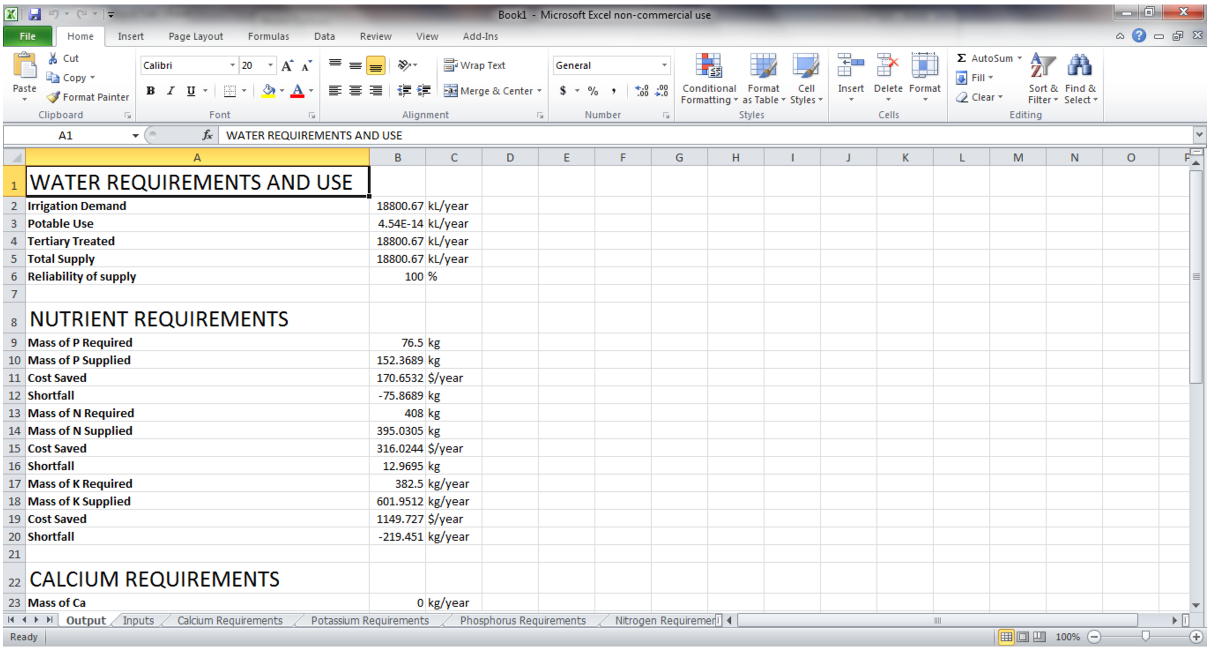
The summary of the results of the simulation appear in the “Output” tab and an example is shown in Figure 32. The following information can be found in this tab:

- Water Requirements and Use – Irrigation demand, a breakdown of annual water usage by source and the reliability of water supply with respect to irrigation.
- Nutrient Requirements – Phosphorus, nitrogen and potassium masses required by the field, quantities provided by irrigation water and the cost offset achieved.
- Calcium Requirements – The average mass of gypsum requires each year to balance out high sodium levels and the rough cost of this.
- Optimization Results – The results of any optimizations run including optimized tank or catchment sizes and the achievable reliability.
- Energy and GHG – a breakdown of energy usage and greenhouse gas emissions for treatment processes broken down by water source.
- Costing – A breakdown of capital and operational costs from treatment processes, broken down by water source.



	A	B	C
1	SPORTSFIELD PARAMETERS		
2	**Turf Type**	Cool Season Turf	
3	**Soil Type**	Good Structure Clay	
4	**Area of Field**	1.7	ha
5	**Level of Growth Required**	Average	
6	**Climate Data**	Keilor	
7	**Clippings Removed?**	TRUE	
8			
9	POTABLE WATER		
10	**Volume Available**	Unlimited	
11	Water Quality		
12	**Sodium**	7.3	ppm
13	**Potassium**	1.35	ppm
14	**Magnesium**	1.85	ppm
15	**Calcium**	9	ppm
16	**Conductivity**	0.1109375	mS/cm
17	**Total N**	0.815	ppm
18	**Total P**	0.007	ppm
19			
20	RECYCLED WATER		
21	**Recycled Water Type**	Tertiary Treated	
22	**Water Available**	Unlimited	
23	**Shandy**	FALSE	

Figure 31: The Input Tab of the produced file



	A	B	C
1	WATER REQUIREMENTS AND USE		
2	**Irrigation Demand**	18800.67	kL/year
3	**Potable Use**	4.54E-14	kL/year
4	**Tertiary Treated**	18800.67	kL/year
5	**Total Supply**	18800.67	kL/year
6	**Reliability of supply**	100	%
7			
8	NUTRIENT REQUIREMENTS		
9	**Mass of P Required**	76.5	kg
10	**Mass of P Supplied**	152.3689	kg
11	**Cost Saved**	170.6532	$/year
12	**Shortfall**	-75.8689	kg
13	**Mass of N Required**	408	kg
14	**Mass of N Supplied**	395.0305	kg
15	**Cost Saved**	316.0244	$/year
16	**Shortfall**	12.9695	kg
17	**Mass of K Required**	382.5	kg/year
18	**Mass of K Supplied**	601.9512	kg/year
19	**Cost Saved**	1149.727	$/year
20	**Shortfall**	-219.451	kg/year
21			
22	CALCIUM REQUIREMENTS		
23	**Mass of Ca**	0	kg/year

Figure 32: The Output Tab of the produced file

4.3 Total Irrigation Chart

The tab labelled “Total Irrigation” contains the chart showing total water use and unmet demand over the source of the simulation. An example of a ten year simulation is shown in Figure 33. This chart will include the volumes used for all water sources.

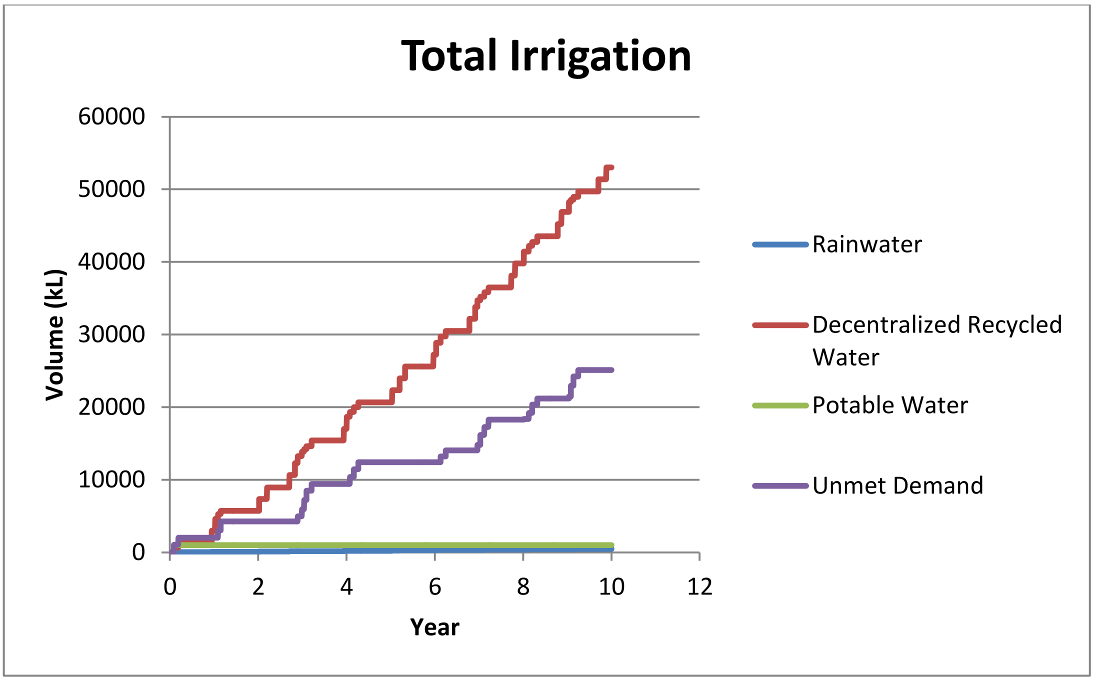


Figure 33: Irrigation Chart detailing water use over ten years

4.4 Tank Levels Charts

The tank labelled “Tank Levels” contains a graph of the amount of water in storage from a particular source over the course of a simulation. An example of a small rainwater tank and catchment is shown in Figure 34. In non-optimized simulation this graph can help the user determine if a tank is over or undersized based around the amount of time it stands full or empty. In the case of rainwater tanks a second line chart for tank inputs is also included to determine how much water is added to the tank on a daily basis.

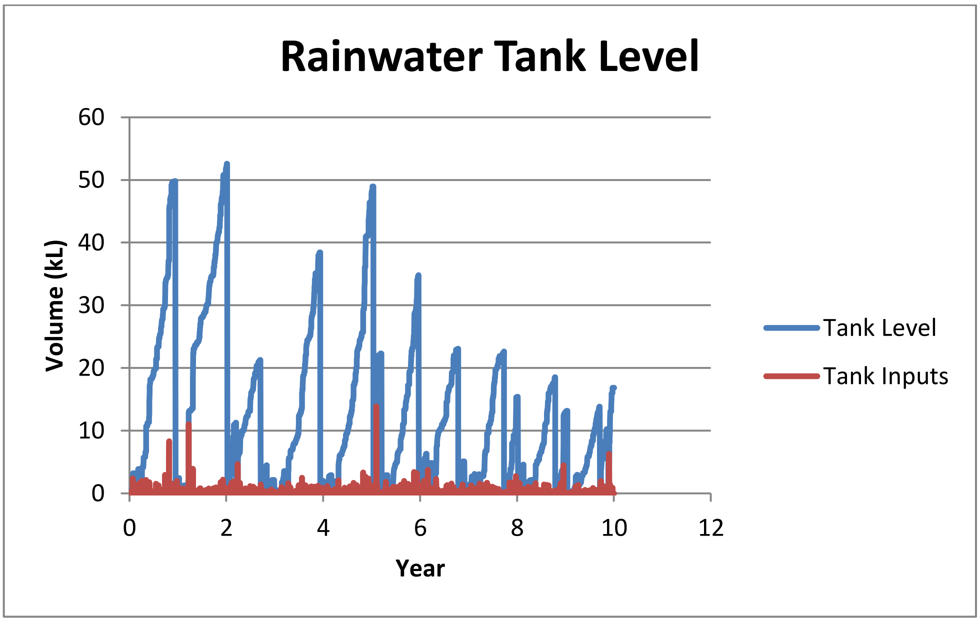


Figure 34: The Tank Level Chart for a rain tank

4.5 Calcium Requirements

The calcium Requirements Chart gives a plot of the demand for calcium in grams over the course of the simulation. An example is shown in Figure 35.

4.6 Potassium, Nitrogen and Phosphorus Requirements

The Potassium, Nitrogen and Phosphorus Requirements Charts, gives a plot of the demand and supplied mass in $kg.y^{-1}$ of each nutrient over the course of the simulation. An example is shown in Figure 36.

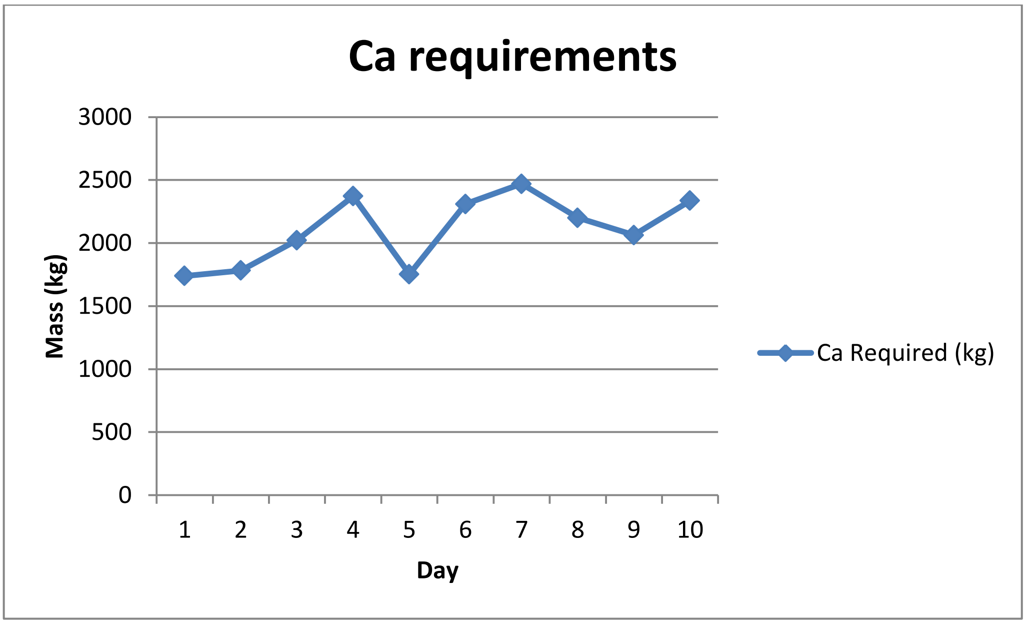


Figure 35: The Calcium Requirement Chart for a high salinity water on a sensitive soil

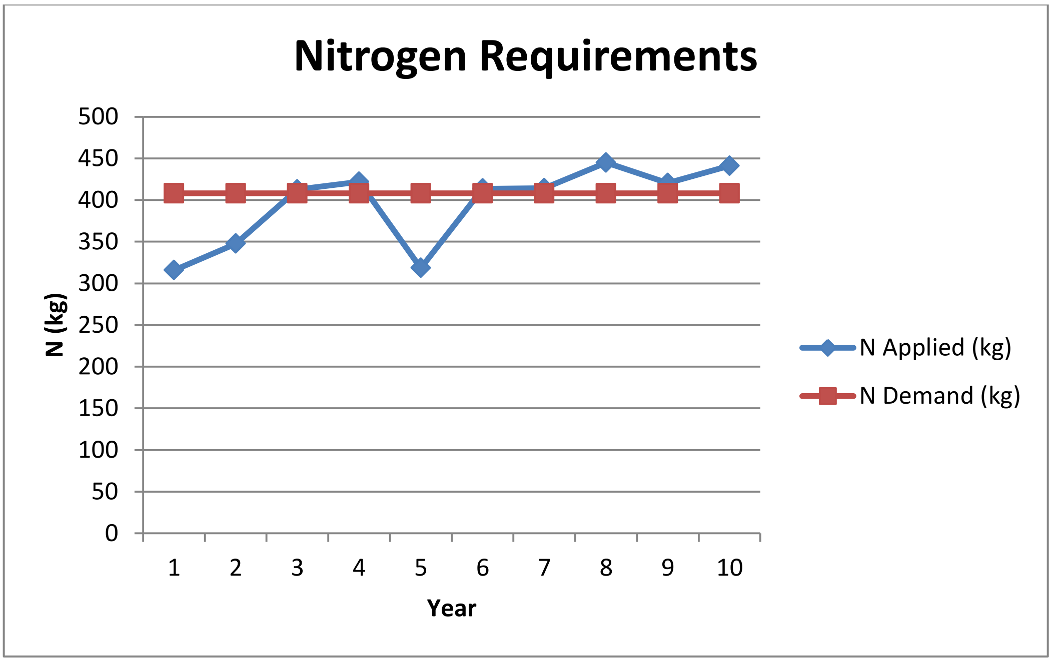


Figure 36: The Nitrogen Requirements Chart for a tertiary wastewater.

5. Conclusions

In conclusion, the Sportsfield Irrigation Software (v. 1.006) has been developed based around the mathematical and logical arguments outlined in this document. The models and estimates have been adapted from existing data to suit the desired model criteria. This has been performed as part of the Smart Water Project Sustainable Water Options for Sportsfields.

The current version of this software was developed based around feedback as part of a validation and testing phase of the project. It will be made generally available in its current form and should be able to be used without the aid of this document.

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Appendix A Changes to Software

V 1.005

- The calculation for field capacity of bush and lawn areas in the Stormwater Catchment Window were updated from:

Soil Texture Type	Field Capacity (mm.cm^{-1})
Sand	0.8
Loamy Sand	1.4
Sandy Loam	2.0
Loam	2.7
Poor-Structured Clay	2.5
Good-Structured Clay	4.0

To:

Soil Texture Type	Field Capacity (mm.cm^{-1})
Sand	0.6
Loamy Sand	0.9
Sandy Loam	1.3
Loam	2.0
Poor-Structured Clay	1.3
Good-Structured Clay	1.9

This brings them into line with the values used in calculations for the minimum growth requirements for sports fields used elsewhere in the software.

- Fixed bug in nutrient calculations for decentralized wastewater use
- Updated estimate for bush evapotranspiration from 1.65 to 1.46 to represent new literature values
- Updated estimate for the base flow recession constant from 0.001 to 0.02 to more accurately reflect literature values.
- Potable water estimates were updated from:

Parameter	Estimate	Form
Sodium (ppm)	6.45	
Potassium (ppm)	0.9	
Magnesium (ppm)	1.5	
Calcium (ppm)	6.15	
Dissolved Solids (mS.cm^{-1})	0.081	Conductivity
Nitrogen (ppm)	0.645	Nitrate
Phosphorus (ppm)	0.001	Total Phosphorus

To:

Parameter	Estimate	Form
Sodium (ppm)	7.3	
Potassium (ppm)	1.35	
Magnesium (ppm)	1.85	
Calcium (ppm)	9	
Dissolved Solids (ppm)	71	Total Dissolved Solids
Nitrogen (ppm)	0.815	Nitrate
Phosphorus (ppm)	0.007	Total Phosphorus

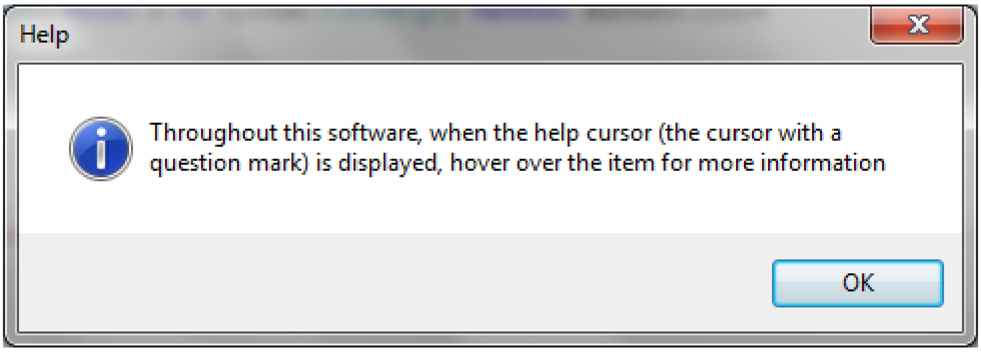
This reflects to values in the 2010 drinking water quality reports.

- Fixed bug in the calculation of N, P and K demand that used N demand in all cases and that incorrectly subtracted the supplied nutrient when determining demand (instead of doing this when calculating the shortfall)

v. 1.006

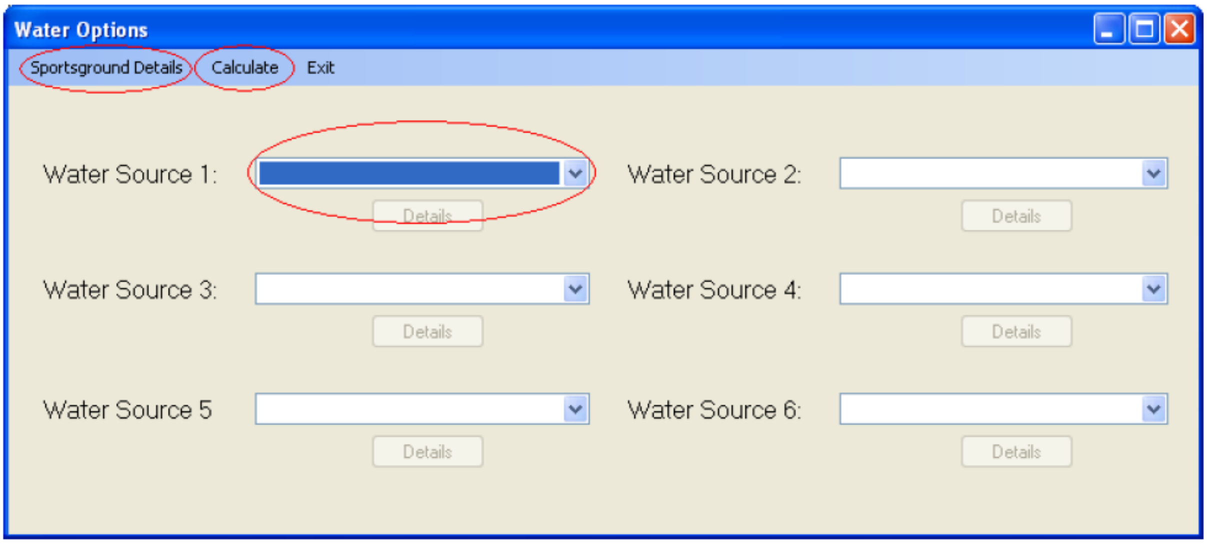
Major Changes

- When the programme opens, the following dialog is displayed:

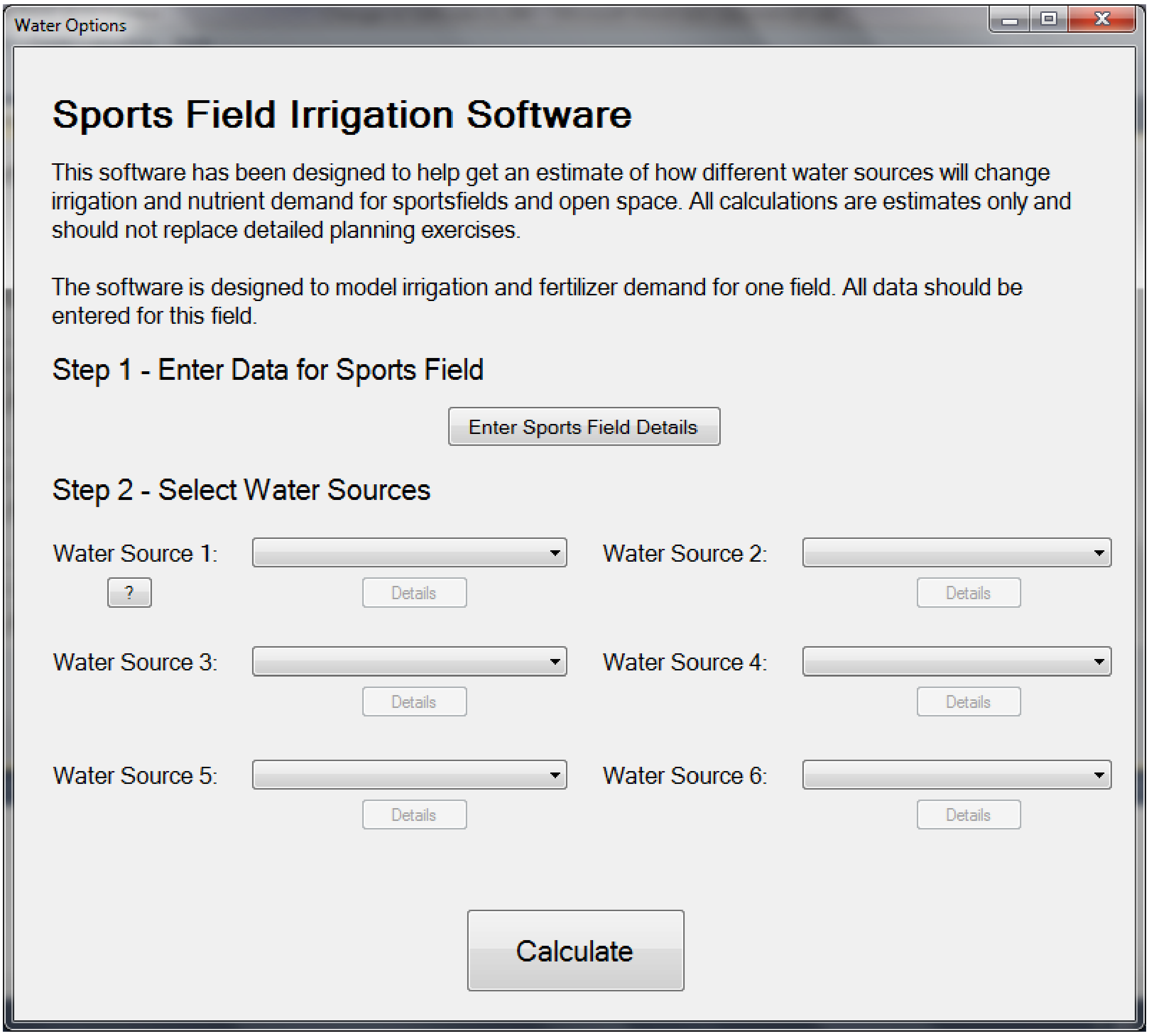


Throughout this software, when the help cursor (the cursor with a question mark) is displayed, hover over the item for more information

- Front page has been altered to more clearly outline the steps required. The menu strip was removed and buttons added for entering the sports field details and for performing the calculation. The initial page was changed from this:



To this:



Sports Field Irrigation Software

This software has been designed to help get an estimate of how different water sources will change irrigation and nutrient demand for sportsfields and open space. All calculations are estimates only and should not replace detailed planning exercises.

The software is designed to model irrigation and fertilizer demand for one field. All data should be entered for this field.

Step 1 - Enter Data for Sports Field

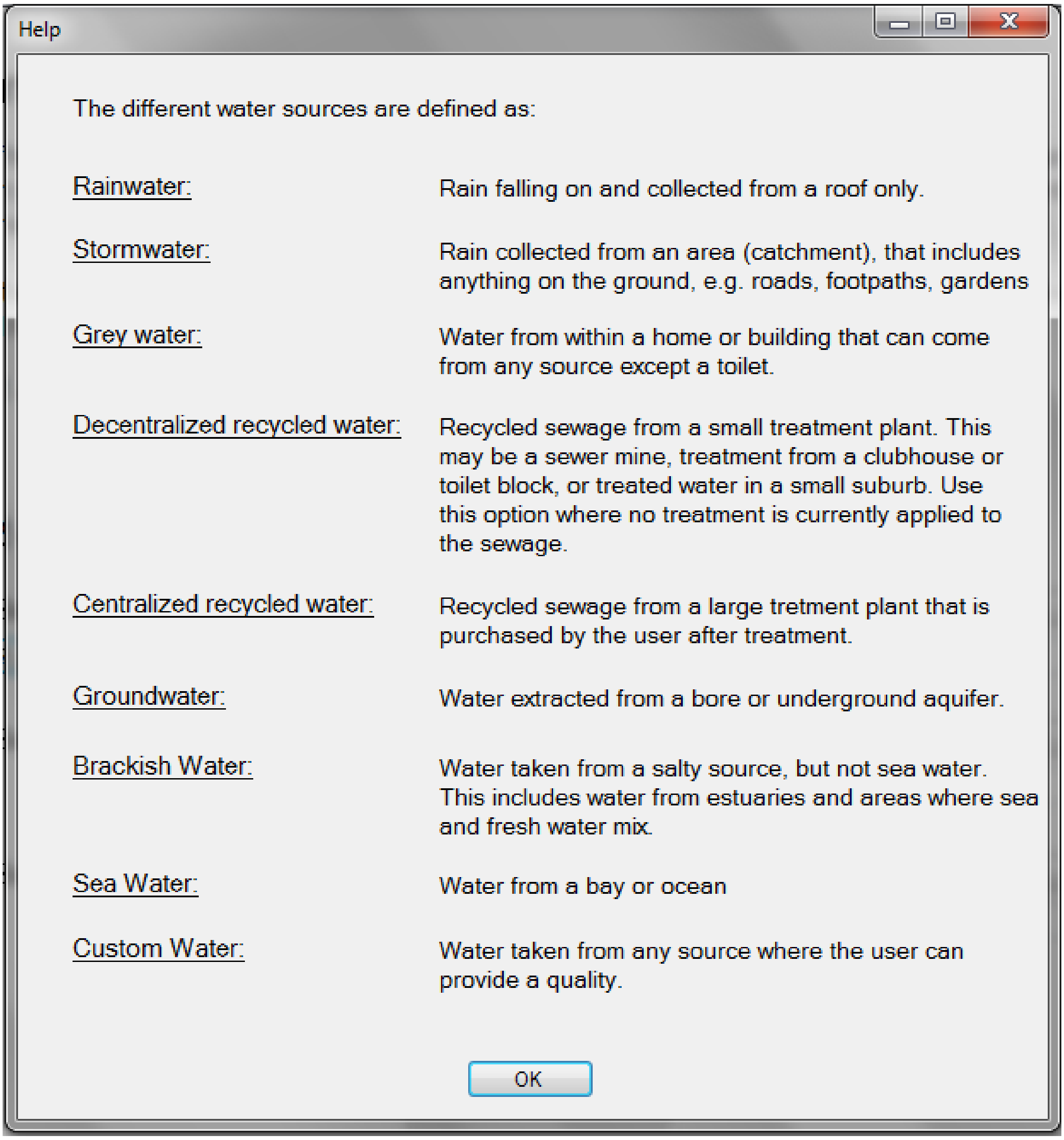
Step 2 - Select Water Sources

N.B. Only the schematic changes are important. Please note that the first screenshot was taken while the programme was running in Windows XP while the second was taken when the programme was running in Windows 7. This is the main reason for differences in the appearance of the window itself.

- After overestimations during trial, Class 1 and Class 2 field levels were removed from the programme
- The term “Level of Field” was changed to “Level of Growth Required”
- In the “Level of Field”/”Level of Growth Required” drop down box, the Classes were replaced with more descriptive phrases:
    - Class 3 became “Strong”
    - Class 4 became “Average”
    - Class 5 became “Just Acceptable”
- Data entered into the Sports Field Data Window, Potable Water Window, Rain Water Window, Brackish Water Window, Custom Water Window, Ground Water Window, Secondary Treated Recycled Water Window, Tertiary Treated Recycled Water Window,

Reverse Osmosis Treated Recycled Water Window, Grey Water Window, Decentralized Recycled Water Window, Sea Water Window, Storm Water Window and Storm Water Catchment Window will be recalled when reopened.

- A “Select All Estimates” button was added to all water quality windows.
- The term “Use System Value” was replaced by “Use Estimate”
- In the main window a “?” button has been added. Clicking this button opens the help window shown below:



The different water sources are defined as:

Rainwater:	Rain falling on and collected from a roof only.
Stormwater:	Rain collected from an area (catchment), that includes anything on the ground, e.g. roads, footpaths, gardens
Grey water:	Water from within a home or building that can come from any source except a toilet.
Decentralized recycled water:	Recycled sewage from a small treatment plant. This may be a sewer mine, treatment from a clubhouse or toilet block, or treated water in a small suburb. Use this option where no treatment is currently applied to the sewage.
Centralized recycled water:	Recycled sewage from a large tretment plant that is purchased by the user after treatment.
Groundwater:	Water extracted from a bore or underground aquifer.
Brackish Water:	Water taken from a salty source, but not sea water. This includes water from estuaries and areas where sea and fresh water mix.
Sea Water:	Water from a bay or ocean
Custom Water:	Water taken from any source where the user can provide a quality.

- In the main window a series of tooltips has been added:
    - Step 2 – Select Water Sources – “Select up to six water sources from the drop down boxes below and click the details button to provide quality and volumes available. Click the "?" for descriptions of different water sources.”
    - Water Source n – “Click the"?" for help on water sources”

  - Details buttons – “Click to provide information on water quality and volumes available”
  - Water source dropdowns – “Click the "?" for descriptions of the water sources”
  - ? button – “Click here for an description of different water sources”
- Potable water and centralized recycled water has now been given an operational cost that can be adjusted in the Potable Water Window. The defaults for potable water and tertiary water were established using the July 2011 costs approved by the Essential Services Commission and averaged across Melbourne. The MF/RO cost default is 95% the cost of potable water and the secondary treated recycled water defaults to the tertiary recycled water cost.
- In the Potable Water Window the following tooltips have been added:
  - Volume Available – “Enter the volume available to the nearest kL or select unlimited.”
  - Volume Available Text Box – “Must be a whole number”
  - Water Quality – “Enter the concentrations of the specified chemicals. If they are unknown select “use estimate”.”
  - Cost – “Enter the cost of potable water in $/kL”
  - Dissolved Salts Form – “Select either conductivity or total dissolved salts from the dropdown menu.”
  - Dissolved Solids – “Enter either the total dissolved salts (TDS) concentration in ppm or the conductivity of the water in mS/cm”
  - Sodium – “Enter the concentration of sodium in the water in ppm.”
  - Potassium – “Enter the concentration of potassium in the water in ppm.”
  - Magnesium – “Enter the concentration of magnesium of the water in ppm.”
  - Calcium – “Enter the concentration of calcium of the water in ppm.”
  - Nitrogen – “Enter the concentration of nitrogen in the water in either ppm total nitrogen, ppm total Kjeldahl nitrogen or ppm nitrate.”
  - Nitrogen Form – “Select either total nitrogen, total kjeldahl nitrogen or nitrate from the drop down menu.”
  - Phosphorus – “Enter the concentration of phosphorus in the water in either ppm total phosphorus or ppm orthophosphate/phosphate.”
  - Phosphorus Form – “Select either total nitrogen, total kjeldahl nitrogen or nitrate from the drop down menu.”
  - All text boxes except Volume Available – “Must be a number.”
  - Use Estimate – “If you are uncertain of a concentration check this box to use an estimate for Melbourne.”
  - Use All Estimates – “Use this button to select all estimates for water quality.”
- In Rain Water Window, adjusted the initial value for reliability to 100%.
- Redefined nitrogen demand for field where clippings are not removed from 24 $g.m^{-2}$ to 0.
- Error in calculation of calcium demand, where the square of the SAR was replaced by 9 regardless of the desired SAR was corrected.
- Water quality data entered in the Custom Water Window are now transferred to the simulation (previously they did not).
- In the Storm Water Window, the treatment regime Wetlands/Disinfection was removed and the treatment Rain Garden was added. The costing models were updated, however the

energy usage and greenhouse gas emissions have not been detailed in the literature and have been assumed to be the same as Wetlands for the moment. The new cost models are:

$$If\ A_{raingarden} < 100\text{m}^2$$

$$\$_{cap_{treatment}} = 0.25 \times A_{raingarden}$$

$$\$_{op_{treatment}} = 0.0125 \times A_{raingarden}$$

$$If\ A_{raingarden} > 100\text{m}^2$$

$$\$_{cap_{treatment}} = 0.137 \times A_{raingarden}$$

$$\$_{oper_{treatment}} = 0.00685 \times A_{raingarden}$$

- The cost models for the wetlands treatment for stormwater were updated. The costing now relies on the wetlands area rather than flow. The new models are:

$$\$_{cap_{treatment}} = 0.0775 \times A_{wetlands}$$

$$\$_{op_{treatment}} = 0.00155 \times A_{wetlands}$$

- In the Storm Water Window, when either the Wetlands or Rain Garden treatments are selected a new numeric appears asking for the area of the treatment as a percentage of the impervious catchment area. The options are 1, 2, 3, 4 and 5% for the wetlands and 0.5, 1, 1.5 and 2% for the rain garden. This assists in calculating the costs and also impacts on the total nitrogen and total phosphorus reductions. The new f_N and f_P factors are:

Wetlands		
Area as % of impervious catchment area	f_N	f_P
1	0.71	0.55
2	0.59	0.39
3	0.52	0.32
4	0.47	0.27
5	0.44	0.25

Rain Garden		
Area as % of impervious catchment area	f_N	f_P
0.5	0.74	0.6
1	0.64	0.25
1.5	0.59	0.19
2	0.56	0.16

- For stormwater treatment systems, the area of the rain garden and the area of the wetlands are now calculated using:

$$A_{wetlands} = \%_{treatmentarea} \times A_{catchment} \times (\%_{roof} + \%_{road} + \%_{pavement})$$

$$A_{raingarden} = \%_{treatmentarea} \times A_{catchment} \times (\%_{roof} + \%_{road} + \%_{pavement})$$

- In the Storm Water Catchment Details Window, the requirement to click the second subsurface tab before continuing has been removed.
- In the Storm Water Catchment Window, the evapotranspiration crop factors and the soil moisture capacity for bushland and gardens is now prefilled. The Use Estimate button for the crop factors has been removed.
- In the Sports Field Details Window the following tooltips have been added:
    - Turf Type - "The turf type is defined as warm- or cool-season. Common warm-season turfs include couch, kikuyu and zoysiagrass, while cool-season turfs include tall fescue, annual bluegrass and kentucky bluegrass"
    - Soil Type – "This is the soil for the root zone or top few cm only"
    - Area of Field – "The area of the field or open space to be irrigated"
    - Level of Growth Required – "The level of growth required of the turf. A turf in high demand for competition would be one requiring strong growth, while one used for training or only casually would need just acceptable growth."
    - Appropriate Climatic Data – "Select the nearest location. Each location represents a weather station with 10 years of data."
    - Are Clippings Removed? – "Are the lawn clippings removed after mowing? This helps to determine fertilizer demand"
- There was a bug that didn't deselect water uses on multiple runs. Ultimately this meant that, for example, if potable water was selected for the first run and was changed to rainwater for the second run, potable water would still be used on the second run. This has been corrected.
- A bug where the stormwater operational costs were missed from the total operational costs calculations has been corrected.
- All output graphs have been altered to use years on the x-axis rather than days. This has, in turn, led to the axis looking less "busy". A secondary result is that the output graph for water use is no longer a stacked graph, but a simple scatter graph.
- In the Sportsfield Details Window a new option for "Comparison" was added under the Turf Type. This will allow the user to perform a simple comparison of potable water use and costs for a warm-season and cool-season turf at the same site.

Minor Corrections

- Corrected Centralized Recycled Water Use variable from "integer" values to "double".
- Typing mistake in Grey Water Optimization Error Window corrected ("Optimiztion" to "Optimization")
- Typing mistake in Centralized Recycled Water Tank Size Optimization Window corrected ("deentralized" to "centralized")
- Error in Brackish Water Tank Size Optimization Error Window corrected ("deentralized recycled water" to "brackish water")
- Error in Seawater Tank Size Optimization Error Window corrected ("deentralized recycled water" to "treated seawater")

- Corrected typo in the Grey Water Window and Decentralized Recycled Water Window. The first tab title was changed from “Known Quantity and Volume” to “Known Quality and Volume”
- In the Local Tab of the Grey Water Window the Treatment drop down menu was changed to a drop down list.
- An error in the output where the decentralized recycled water treatment was given the heading “Rain Water Treatment” has been corrected.