CRC for
Water Sensitive Cities

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

SUWMBA User Manual

Site-scale Urban Water Mass Balance Assessment Tool

Version: 2 (beta version for testing)

Australian Government
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User Manual for Site- scale Urban Water Mass Balance Assessment (SUWMBA) Tool Version: 2 (beta version for testing)

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Availability:

This beta version (V2) is made available to CRCWSC researchers and partners for testing purposes.

Context

Additional information on the context of development of this tool and the associated user manual can be found in the *Infill Performance Evaluation Framework*; its application to case studies in Salisbury (in Adelaide) and Knutsford (in Perth); and the *Infill Typologies Catalogue* (see https://watersensitivecities.org.au/content/project-irp4/.)

Limitation statement

The beta version of SUWMBA Tool is provided free of charge for testing, evaluation, and feedback purposes by the CRC for Water Sensitive Cities on an 'as is' basis. By using this tool, users acknowledge no guarantee, either expressed or implied, is given on the accuracy or completeness of the tool or that it is free from error.

The tool can be used only for general guidance about the water performance of urban units and the extent to which various water sensitive interventions can influence the performance. It is not suitable for the detailed design of water sensitive interventions and cannot replace professional judgement. Users should consult with qualified and experienced architects and engineers to finalise and validate designs.

The tool can be used only for urban units up to 4 ha. If no rainwater harvesting system exists, it can be used up to 50 ha. For large urban units or units with non-uniform land use (i.e. low-density and high-density residential), users need to divide the urban unit to smaller, uniform units, and then add up the urban water mass balance of divided units to quantify the water performance of the whole. Failure to meet any of these requirements may invalidate the analysis.

Contents

Glossary

Aquifer	In this manual, aquifer refers to a shallow groundwater resource, as distinct from a deep groundwater resource.
BOM	Bureau of Meteorology
Built form	The human-made surroundings that provide the setting for human activity, ranging in scale from buildings to parks.
Catchment	This manual uses the hydrological meaning of catchment, which is an area of land where surface water converges to a single point (drainage basin).
CRCWSC	Cooperative Research Centre for Water Sensitive Cities
Evaluation framework	A structure and analysis process used to collate, organise and link evaluation questions, outcomes or outputs, indicators, data sources, and data collection methods. In this manual, the evaluation framework refers to evaluation of an 'urban entity' – i.e. the components within a three-dimensional physical boundary (see 'urban entity').
Evapotranspiration	The process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces, and by the transpiration of plants
Field capacity	The amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased
Infiltration	This manual defines infiltration as the water that enters the soil, percolates through the soil, and passes out of the urban area boundary, 1 m below the surface. This process can also represent groundwater recharge if we assume the infiltrated water continues to sub-surface aquifers.
Impermeable	Impermeable is the opposite of permeable. See 'permeable'.
Impervious	Impervious is the opposite of pervious. See 'pervious'.
Impervious fraction	Percentage of a site that is effectively impervious
Imported water	Water sourced from outside the urban system, such as centralised supplies from dams, groundwater reserves, seawater, etc. It is distinct from water sourced from within the urban system, such as harvested rainwater and stormwater, recycled wastewaters, etc.
Internally-sourced water	Water harvested/generated within the 'entity' or urban system (rainwater, stormwater, recycled wastewater) which is used often referred to as 'decentralised' water (but can be centrally managed)
Mass balance	A type of material flow analysis that generates a comprehensive account of the flows of a resource into and out of an entity/system (sum of the inflow equals sum of the outflows and the change in storage), with the change in storage acting as a check for the conservation of mass. See also water mass balance.
MUSIC	The Model for Urban Stormwater Improvement Conceptualisation helps urban stormwater professionals visualise possible strategies to tackle urban stormwater hydrology and pollution impacts.
Natural water flows	Water flows in the natural water cycle; i.e. precipitation, stormwater runoff, infiltration to aquifers and groundwater and evapotranspiration. It is distinct from anthropogenic (man-made) water flows.

Permeable	Relating to materials that allow the passage of water. It is distinct from ‘pervious’. In this manual, we use it to refer to permeable paving.
Pervious	Admitting passage; i.e. capable of being penetrated by water. A pervious surface allows water to penetrate through the surface. It is distinct from ‘permeable’. In this manual, we refer to the pervious/impervious fraction of a surface relating to hydrological modelling.
Pervious fraction	Percentage of a site that is effectively pervious. It is the opposite of ‘impervious fraction’.
Precipitation	Rainfall
Recharge	Water that infiltrates through the soil beyond the urban area boundary (i.e. 1m below the surface) into a shallow aquifer. It is referred to as deep percolation in MUSIC and BOM.
Site	A piece of land where development occurs; e.g. single or multiple residential dwellings on a piece of private land; a large parcel of land with multiple buildings.; or sometimes a small number of 'lots' combined.
Stormwater discharge	Stormwater runoff that is discharged from the study area. It may be a fraction of the original amount of runoff, considering some may drain to pervious surfaces and infiltrate, or be taken up by vegetation and evapotranspire. See also ‘stormwater runoff’.
Stormwater runoff	Rainfall that flows over the ground surface. It is created when the amount of rain that falls on ground surfaces is higher than storage or infiltration capacity.
SUWMBA	The Site-scale Urban Water Mass Balance Assessment (SUWMB) Tool is a daily urban water balance model that simulates the urban water cycle specifically for urban developments at the site scale. It concurrently examines the influence of both the built form design and water servicing features. See Moravej et al. (in prep.) for more information.
Supply internalisation	Sourcing of water from within the urban system, to reduce reliance on water sourced from the supporting environment
Urban	A location characterised as population clusters of 1,000 or more people, with a density of at least 200/km^2 (ABARE, 2016)
Urban area	The two-dimensional (area-based) boundary of the ‘urban entity (three-dimensional boundary)’. The area being evaluated could be the site, or the broader area in which a site being evaluated is located.
Urban unit physical boundary	The physical three-dimensional envelope surrounding the urban area being evaluated, to the height above the tree line and to a depth of 1 m below the ground surface.
Urban entity	The three-dimensional ‘system’ being evaluated for performance. It includes ‘urban elements’ such as the buildings (and water consuming appliances), water, infrastructure (piped and natural flows and related treatment systems), landscape (to 1m depth of soil) and associated land surfaces and vegetation, and related water storages. This term is used interchangeably with ‘urban area’ in this manual. Urban entity can be seen as ‘control volume’ considered in engineering field for applying continuity equation (i.e. mass balance).
Urban system	The combination of physical areas and technical systems associated with the urban area being assessed. It includes built forms and landscapes within the physical urban area (see ‘urban unit physical boundary’) and also the water services that draw from urban catchments, which may be outside the urban area being assessed.

Urban water efficiency	In this manual, water efficiency is considered in terms of the urban area being evaluated, and how efficient is the freshwater consumption of the urban area. Hence, it is the volume of freshwater (sourced from outside the urban system) consumed in the urban area, per capita of population living in the urban area. This manual uses the term 'urban water efficiency' to distinguish it from other uses of ' water efficiency' (such as 'end-user water efficiency' or 'appliance water efficiency').
Urban water mass balance	An equation that describes the flow of water in and out of an urban entity (sum of the inflow equals the sum of the outflows and the change in storage), with the change in storage acting as a check for the conservation of mass
Water performance	In this manual, water performance describes a set of performance objectives related to the protection and functionality of water in the urban landscape. It includes the maintenance of natural water flows, water resource management, and water-related amenity. It captures the biophysical qualities of a water sensitive city.
Water sensitive	Having the attributes of a water sensitive city
Water sensitive city	A vision for urban water management that: requires the transformation of urban water systems from a focus on water supply and wastewater disposal to more complex, flexible systems that integrate various sources of water; operates through both centralised and decentralised systems; delivers a wider range of services to communities; and integrates into urban design (Wong and Brown, 2009).

1. Introduction

Managers of urban area and urban water systems are investigating water sensitive urban design (WSUD) and water servicing options to mitigate the effects of urbanisation on natural hydrological flows, increase water efficiency, and improve resilience to droughts and floods. They increasingly need to know the current water sensitive performance of urban areas in relation to these objectives, what the desired water performance should be, and the extent to which various interventions can influence that performance. Understanding and managing water sensitive performance requires quantifying the water flows associated with an urban area.

The Site-scale Urban Water Mass Balance Assessment (SUWMBA) Tool does this by performing an urban water mass balance, which is a comprehensive account of all water flows in both the natural and anthropogenic water cycles (rainfall, evapotranspiration, stormwater runoff, imported water, decentralised water, wastewater, etc.). The water flows are estimated as annual volumes using daily time-step calculations. It provides a snapshot of all flows into, out of, and through an urban area, from which performance indicators can be derived.

In particular, the tool implements an urban water mass balance of a three-dimensional space/volume for all flows of water and water stored within that volume (e.g. in soil and rainwater tanks). Typically, the vertical boundary of this system is from the top of roofs/tree canopy to a depth of 1 m below the land surface. Throughout this document, the ‘space/volume’ assessed is referred to ‘urban entity’.

In assessing urban water mass balance, the sum of all inputs equals the sum of all outputs accounting for change of water stored within the entity. We use the mass balance approach to evaluate how the design of the urban entity influences all flows of water.

1.1 SUWMBA overview

The SUWMBA Tool is developed in Visual Basic for Microsoft Excel (Excel-VBA). It performs four main steps (see Figure 1):

1. Defines the urban entity to be assessed
2. Inputs parameters needed to estimate urban water flows (environmental context, areas of constituent land use or surfaces, water harvesting, and water uses)
3. Compiles the urban water mass balance, and
4. Generates water sensitive performance indicators.

The inputs to the tool are:

1. site information (e.g. population, number of dwellings)
2. environmental context (e.g. location, timeframe of analysis)
3. zones within the area (e.g. land cover areas and their characteristics)
4. usages of alternative water sources (rainwater harvesting, purple pipe, etc.)
5. water demand and use (indoor and outdoor water characteristics, etc.)
6. hydrological model settings.

The outputs from the tool are:

1. an annual urban water mass balance for the assessed urban entity
2. a set of quantified water sensitive performance indicators derived from the urban water mass balance data.

The tool can be used as a component of the Infill Performance Evaluation Framework published by the CRC for Water Sensitive Cities (CRCWSC) (Renouf et al., 2020).

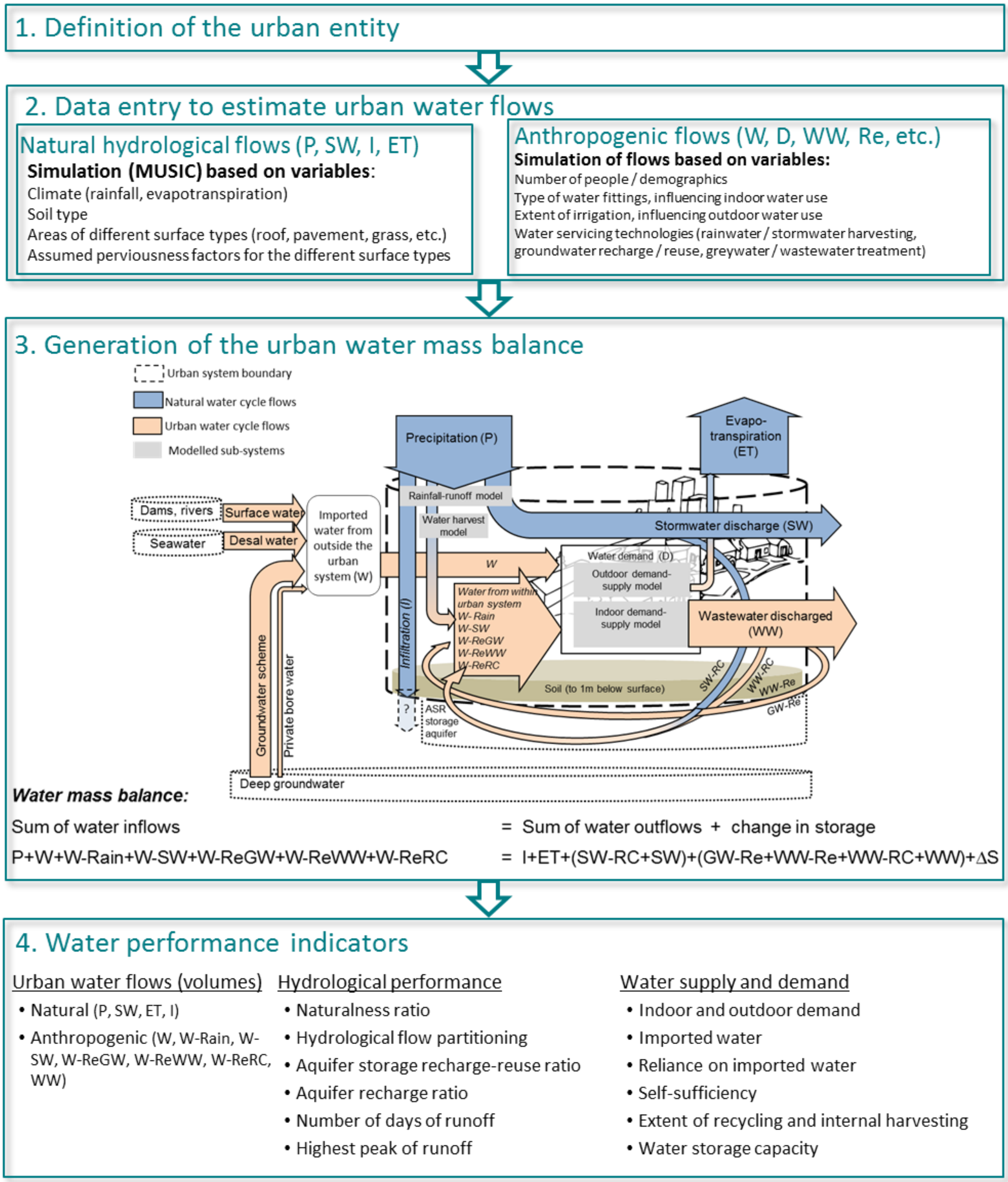


Figure 1. Steps performed in the Site-scale Urban Water Mass Balance Assessment (SUWMBA) tool

Note: See Figure 2 (p. 16) for a complete list of abbreviations.

1.2 Conditions of use

The SUWMBA Tool V2 belongs to the CRCWSC. It is freely provided to researchers and partners of the CRCWSC for testing and development purposes but is not proposed for any commercial or applied use without further detailed testing.

The tool can be used only for urban units up to 4 ha. If no rainwater harvesting system exists, it can be used up to 50 ha. For large urban units or units with non-uniform land use (i.e. low-density and high-density residential), users must divide the urban unit to smaller, uniform units, and then add up the urban water mass balance of divided units to quantify the water performance of the whole. Failure to meet any of these requirements may invalidate the analysis.

The tool is developed for desktop computers and laptops using the Microsoft operating system environment. It may not work properly using an Apple Macintosh operating system, tablets and phone devices, and/or systems in other languages than English. The minimum system requirements are:

1. an English version of Microsoft windows XP service pack 3 (or later).
2. an English version of Microsoft Office (Excel) 2010 (or later).
3. an Intel Pentium III processor, 500 MHz (or greater).
4. a 256 MB RAM (or greater)
5. a 100 MB hard disk.

1.3 Intended uses and users

The tool is useful for anyone interested in a holistic understanding of the water flows and water sensitive performance of urban entities. This includes urban water managers and professions, urban designers and planners, architects, urban researchers and students. The tool emphasises the performance of the urban entities, rather than the performance of water systems (i.e. piped networks) within urban areas.

The tool can be used to:

- quantify the baseline water sensitive performance of an urban entity
- inform water sensitive performance objectives and targets
- evaluate and compare different urban forms, and different water servicing and use scenarios, to screen various water sensitive interventions
- evaluate the influence of different environmental conditions on water sensitive performance.

The tool can be used only for general guidance about the water performance of urban entities and the extent to which various water sensitive interventions can influence the performance. It is not suitable for the detailed design of water sensitive interventions and cannot replace professional judgement. Users should consult with qualified and experienced architects and engineers to finalise and validate designs.

1.4 Related documents

The SUWMBA Tool is based on the concept of urban water mass balance (Farooqui et al., 2016; Kenway et al., 2011; Renouf et al., 2018) and quantification of urban water performance indicator (Renouf et al., 2019; Renouf et al., 2017).

A detailed description of methods incorporated in the tool can be found in Moravej et al. (in prep.). An example use of the tool for quantifying the hydrological performance of ‘business as usual’ and water sensitive alternatives of infill development is presented by Renouf et al. (2019).

The tool can be used alongside other performance evaluation processes such as urban heat, liveability, and green space quality. An example for infill development is provided in the *Infill Performance Evaluation Framework* developed by Renouf et al. (2020).

The tool can be used to quantify water performance of a range of development typologies, for example, the *Infill Typologies Catalogue* developed by London et al. (2019).

1.5 General features of the SUWMBA Tool

The urban entity assessed in SUWMBA is defined by the urban system boundary (see Figure 1). It is horizontally defined by the spatial scope of the piece of urban landscape being assessed (defined by the user). It can range from one single lot to a mix of different land covers up to 4 ha (some examples are provided in

Table **1**). Vertically, it is defined from rooftops/treetops to the root zone (i.e. 1 m below surface). This urban system boundary definition gives a three-dimensional volume (i.e. urban entity), the water mass balance of which the tool estimates.

Table **1** shows some of the features of the urban entity and the SUWMBA Tool to estimate its urban water mass balance and water performance.

Table 1. Features of each analysis mode in the SUWMBA Tool

Examples of urban entities	Single site or lot Apartment complex Resort complex Large developments including a mix of typologies up to 4 ha
Urban features typically present	**Individual** public or private urban features: • residential dwellings (houses, apartments) • public open spaces • roads and road reserves (e.g. streetscape features)
Zones within the urban entity	Defined by the **surface category** (maximum of 20 zones)
Estimation of the areas of the zones	Areas of each (**ground surface type**) zone calculated from dimensions in design drawings of the assessed urban entity
Imperviousness	Impervious factors for each **ground surface type**
Estimation of natural hydrological flows (runoff, infiltration, evapotranspiration)	Simulated using modified MUSIC rainfall-runoff model algorithms, based on a daily time step Options to use default impervious fractions for **surface type** or enter customised values
Estimation of rainwater harvesting	Simulated using a simple model, based on roof area, storage capacity, and water demand
Estimation of water demand	Simulated using a household water demand model, based on household demographics, appliance features and outdoor irrigation

2. Structure of the tool

Table 2 lists the worksheets contained in the tool. Only the START and INPUT-Site sheets are initially visible to the user. The RESULTS sheet becomes visible once the calculations have been performed. The START sheet provides general information about the tool (e.g. version). The INPUT-Site sheet is the starting point for using the tool. Users enter the required data in the following fields:

1. **Site information**, including the area, population, and dwellings of the urban entity to be assessed
2. **Environmental context** (the geographic region and year), which determines the climate and soil to be used in the analysis. Data libraries can be replaced with customised or more up-to-date values on the 'INPUT-user defined data' sheet.
3. **Zones within the site**, which represent ground surface types present in the assessed urban entity
4. **Water harvesting** parameters (defining harvested surfaces, storage capacity and uses of harvested water, or selecting rainwater use)
5. **Water demand** parameters (selecting parameters corresponding to indoor and outdoor water demand)
6. **Hydrological model settings**, which define the parameters used by the hydrological model.

Table 2. Worksheets within the SUWMBA Tool

Worksheet name	Description
START ►►	General information about the SUWMBA Tool
INPUT – Site	Input of parameters
INPUT – User-defined data	Input of user-defined climate data (rainfall and evapotranspiration) to replace the in-built library values
RESULTS – Site 1 (2,3,4,5,…)	Results generated for the analysed urban entity – urban water mass balance, performance indicators, and a summary of user inputs
MODEL – Input summary - Site	Collation of the input data used in the analysis, including user-defined inputs and data extracted from data libraries
MODEL - MUSIC – Site	Modified algorithms from the MUSIC rainfall-runoff model for estimating the natural hydrological flows (runoff, evapotranspiration, infiltration) and irrigation Algorithms for rainwater harvesting systems
Calculation – Site	Aggregation of the urban water flows for each zone and calculation of water performance indicators based on the estimated urban water flows
LIBRARY – Rainfall	Rainfall data
LIBRARY – PET	Potential evapotranspiration (PET) data
INDEX	Index of input parameters and modelling options
VERSION LOG	Record of tool updates

Enter input data in the orange-shaded cell, either by selecting from a drop-down menu or entering values directly (see Table 3). Once all the required data has been entered, click the 'Start calculation' button to perform the calculations, and generate the results.

Outputs presented in the RESULTS sheets include a water mass balance containing estimates of all urban water flows, and the quantified water sensitive performance indicators that are derived from the flow data.

2.1 Inputs

Table 3 summarises the inputs required to run the tool.

Table 3. Inputs for site-scale analysis

Section of the tool	Parameters	Comment
Site information	Region	Enter the location of the site (text)
	Scenario name	Enter the name of current scenario (text)
	Total area (m^2)	Enter the total area of assessed urban entity (value in m^2)
	Total population	Enter the total population of assessed urban entity (number of people)
	Number of dwellings	Enter total number of dwellings in the assessed urban entity (value)
Environmental context	Rainfall data	Select location (BOM station) for the precipitation data (see Table **11**)
	Year	Select the year for precipitation and potential evapotranspiration data (see Table **11**)
	Soil type	Select region for the soil data (see Table 8 or alternatively select based on soil types using values in Table 9)
	Potential evapotranspiration data	Select hydrological catchment for the PET data (see Table **11**)
Zones within the site	Surface descriptions	Enter text to describe each surface type present in the assessed urban entity
	Surface categories	Select from menu the category of each surface category (see Table 5)
	Areas of zones (m^2)	Enter value. The area of each surface category can be measured from development layout plans or architectural designs
	Impervious fraction (%) of each zone	Default value auto-generated (see Table 5). Alternative value can be entered.
Water harvesting	Connection to rainwater tank	Indicate with yes or no, the surfaces connected to a rainwater storage tank
	Roof surface type	Select from menu (see Table **6**)
	Roof surface runoff coefficient	Default value auto- generated[1] (see Table **6**). Alternative value can be entered. This parameter is also called 'roof coefficient' in literature.
Water demand and use	5A. Outdoor water demand	
	Pervious/vegetation type	Select from menu (see Table 7)

Section of the tool	Parameters	Comment
	Evapotranspiration factor	Default value auto-generated[1] (see Table 7). Alternative value can be entered. This factor is also called 'crop factor' in the literature.
	Irrigation of outdoor surfaces	Indicate with yes or no, the surfaces that are irrigated [1]
	5B. Household water demand and use	
	Capacity of rainwater tank (L)	Enter value in L
	Initial water storage in the rainwater tank (%)	Enter initial water storage in the rainwater tank as a percentage of its capacity
	Rainwater tank capacity needed to meet 100% non-potable demand (L)	Enter value
	Uses of harvested rainwater	For each water use, indicate with yes/no if harvested rainwater is used
	Type of washing machine	Select top loader or front loader
	Mode of dishwasher operation	Select economy mode or not
	Water efficiency rating of appliances and fittings	Select the WELS water efficiency rating (1–6) for showers, taps, washing machine, dishwasher
	Capacity of washing machine (kg), dishwasher (settings), bath (L)	Enter values
	Duration of tap use	Select less than or more than 20 seconds
	Number of people per dwelling	Enter value
	Number of adults	Enter value
	Number of teenagers	Enter value
	Number of children (4–12 years)	Enter value
	Number of children (0–3 years)	Enter value
	Household annual income (AUS$)	Select the ranges from the drop-down menu
Hydrological model settings	Soil moisture store capacity (SMSC)	Default value auto-generated (based on soil region). Alternative value can be entered.
	Field capacity (FC)	Default value auto-generated (based on soil region). Alternative value can be entered.
	Impervious threshold (IMPSC)	Default value auto-generated (based on soil region). Alternative value can be entered.
	Initial soil storage (ISS)	Default value auto-generated (based on soil region). Alternative value can be entered.
	Infiltration capacity (COEFF)	Default value auto-generated (based on soil region). Alternative value can be entered.
	Infiltration exponent (SQ)	Default value auto-generated (based on soil region). Alternative value can be entered.
	Daily recharge rate (S)	Default value auto-generated (based on soil region). Alternative value can be entered.
	Irrigation trigger (IRRT)	Default value auto-generated. Alternative value can be entered.
	Impervious fraction of pre-development (i.e. natural state)	Default value auto-generated. Alternative value can be entered.

Section of the tool	Parameters	Comment
	Consumptive water usages and leakage (as % of imported water)	Default value auto-generated. Alternative value can be entered.

1. If use of rainwater for irrigation is not selected, the tool will assume that potable water is used for any irrigation demand selected in Section 5A.

2.2 Outputs

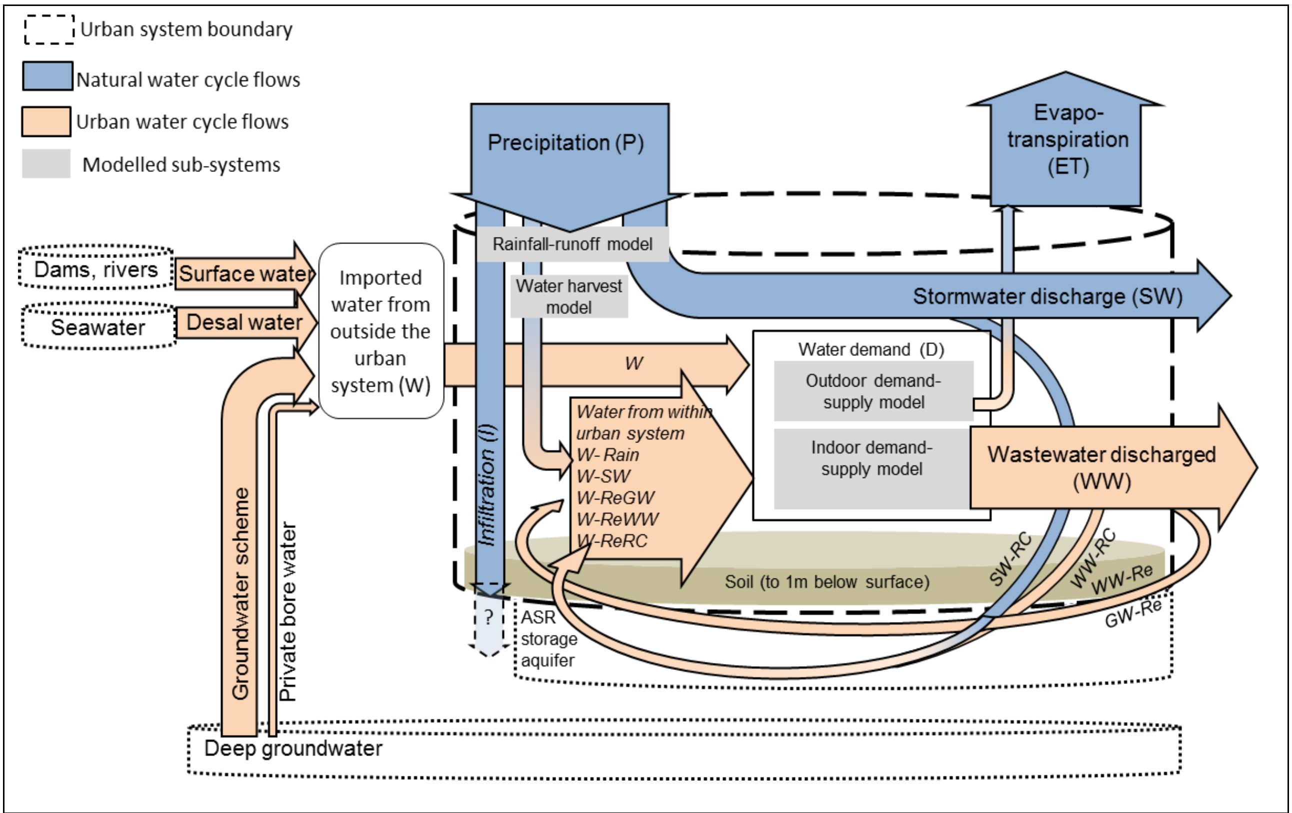
Outputs of the SUWMBA tool include urban water mass balance (Figure 2) and water performance indicators
(

Table **4**). The urban water mass balance of the assessed urban entity is based on the principle of mass conservation (i.e. sum of inflows = sum of outflows + change in storage). Water is incompressible under normal conditions, so urban water mass balance flows can be expressed as volumes. The SUWMBA tool can show the impact of water sensitive interventions (e.g. change in land covers) on urban water flows.

The water performance indicators are derived from the urban water mass balance flows and based on those developed by Renouf et al. (2020) and Renouf et al. (2017) for the *Infill Performance Evaluation Framework*. There are two types of indicator:

- ‘end-point’ indicators are performance criteria at or close to the end-point of the cause-effect chain
- ‘ mid-point’ indicators represent the contributing factors along the cause-effect chain that could be used as proxies.

Table **4** presents the full list of indicators.



Flows in the natural water cycle:

P	= precipitation (minus harvested rainwater and stormwater)
I	= infiltration through 1m soil profile
ET	= evapotranspiration
SW	= stormwater discharged from the urban system
∆S	= change in storage (soil moisture and stored water)

Flows in the urban water cycle:

D	= water demand
W	= water imported from outside the urban system (mains water)
W-Rain	= water from rainwater harvesting
W-SW	= water from stormwater harvesting
W-ReGW	= water from recycled / reused greywater
W-ReWW	= water from recycled wastewater
W-ReRC	= water recovered from recharged aquifer storage
SW-RC	= stormwater recharged to storage aquifer
SW	= stormwater discharged from the urban system
GW-Re	= greywater collected for recycling / reuse in the urban system
WW-Re	= wastewater collected for recycling / reuse in the urban system
WW-RC	= wastewater recharged to storage aquifer
WW	= wastewater (including greywater) discharged from the urban system

Water mass balance:

Sum of water inflows	= Sum of water outflows + change in storage
P+W+W-Rain+W-SW+W-ReGW+W-ReWW+W-ReRC	= I+ET+(SW-RC+SW)+(GW-Re+WW-Re+WW-RC+WW)+∆S

Figure 2. Urban water mass balance

Table 4. Water performance indicators

Mid-point indicators	Unit
Site's built area fraction	Percentage (%)
Site's vegetated area fraction	Percentage (%)
Permeable fraction of hard surfaces	Percentage (%)
Site's overall impervious fraction	Percentage (%)
Vegetated fraction irrigated	Percentage (%)
Indoor water demand per capita	L/person/day
Outdoor water demand per capita	L/person/day
Extent of wastewater recycling	Percentage (%)
Extent of water harvesting	Percentage (%)
Water supply self-sufficiency	Percentage (%)
Water storage capacity (in soil), for supporting vegetation and cooling	kL
Water storage capacity (in reservoirs), for reducing peak stormwater flows – total volume	kL
Water storage capacity (in reservoirs), for harvesting – effective volume	kL
End-point indicators	
SW runoff coefficient (hydrological flow partitioning: % precipitation that becomes runoff)	Percentage (%)
SW runoff naturalness ratio	Percentage (%)
Number of days of runoff (over assessed timeframe)	–
Highest peak volume for a maximum intensity rainfall event	ML
Infiltration coefficient (hydrological flow partitioning: % precipitation that infiltrates into soil)	Percentage (%)
Infiltration naturalness ratio	Percentage (%)
Aquifer recharge coefficient (hydrological flow partitioning: % precipitation that is recharged to shallow aquifer)	Percentage (%)
Aquifer storage recharge: reuse ratio	Percentage (%)
Evapotranspiration coefficient (hydrological flow partitioning: % precipitation that is evapotranspired)	Percentage (%)
Evapotranspiration naturalness ratio	Percentage (%)
Water supplied from the environment, per capita	L/person/day
Reliance on centralised supply	Percentage (%)

2.3 Models used within the tool

Rainfall–runoff model for estimating natural hydrological flows

The SUWMBA Tool uses a modified rainfall–runoff algorithm from the MUSIC (Model for Urban Stormwater Improvement Conceptualisation) (eWater, 2017) model to estimate the annual natural hydrologic flows for the assessed urban entity (runoff, evapotranspiration and infiltration to groundwater). This model performs a daily time-step analysis to predict how much of the daily rainfall will become runoff, evapotranspiration or infiltrates to groundwater. The estimated daily volumes are then aggregated to annual totals.

The main variables are daily rainfall, daily potential evapotranspiration, soil type (influencing soil store capacity and field store capacity), and the imperviousness of the surfaces present in the assessed urban entity. These are defined by the environmental context and types of zones in the assessed urban area. Other model variables are the impervious threshold, initial soil storage, infiltration capacity, infiltration exponent, and daily recharge rate. Default values are set within the tool, but these can be replaced by other values if necessary.

In cases where rain water is harvested, harvested amounts are subtracted from the daily rainfall amounts. In cases where irrigation is performed, the applied irrigation water is assumed to be applied to the pervious fraction of the zone, and to evapotranspire and infiltrate accordingly.

Modelling natural hydrological flows on an annual basis produces a difference between the amount of inputs (i.e. precipitation) and the amount of outputs (i.e. evapotranspiration, runoff, infiltration). The difference is changes in soil moisture content and other storage (i.e. rainwater tank).

Rainwater harvesting model

Rainwater harvesting and use is simulated daily using a continuous water mass balance model for rainwater tanks developed by Fewkes and Butler (2000). The model considers the amount of harvestable water from the roof (based on precipitation, a roof surface runoff coefficient and the area of the roof connected to the rainwater tank), daily water demand (for selected indoor and outdoor water demand), the size of the rainwater tank, initial water storage in the rainwater tank, and a 'yield-before-spill' operating rule.

The model assumes the following:

- The connection of a zone to rainwater harvesting implies the whole area of the zone is harvested (perimeter of the area is connected to gutters and all gutters are connected to the rainwater tank).
- First flush diverters are not employed.
- Demand is met by the harvesting rainwater at the end of the day, meaning temporal variations in rainwater harvesting and water demand throughout the day are not considered.
- All the water demand is met either from harvested rainwater or another water source. For the components that are linked to the rainwater tank, rainwater comes with higher priority and if there is no rainwater in the tank, external water is used to fulfil that component. The only exception is irrigation demand for purple pipe where irrigation is met by purple pipe first.

Water demand model

Indoor and outdoor water demand are calculated separately. Indoor water demand is modelled using an urban water demand model developed by Makki et al. (2015). The variables are the demographic makeup of the household and the water efficiency of household appliances (see Table 3). Indoor water demand is considered non-seasonal due to low temporal fluctuation (Makki et al., 2015; Beal and Stewart, 2011; Loh and Coghlan, 2003).

By contrast, outdoor water demand is highly seasonal and is modelled as an add-in to the MUSIC rainfall–runoff model. The model assumes the aim of irrigation is to keep soil moisture at readily available water (RAW) content defined by irrigation trigger factor (IRRT). If the soil moisture falls below a percentage of field capacity (FC) determined by IRRT (i.e. IRRT × FC), the deficiency is met through irrigation. Note that IRRT = 1 means irrigation applies to keep the soil moisture at field capacity. Potential evapotranspiration is adjusted for different types of pervious/vegetation cover using an 'evapotranspiration' factor (also commonly referred to as 'crop' factor) that is defined by the user. Note evapotranspiration factor = 1 means the evapotranspiration rate of the pervious fraction of the zone is equal to potential evapotranspiration.

The model assumes the following:

- The original indoor water demand model from Makki et al., (2015) is derived based on data collected from south east Queensland households. The model assumes the same relationships between the influencing factors and household water demand is valid for the rest of Australia.
- The amount of daily irrigation is defined by the deficiency of water to the field capacity determined by IRRT. In other words, irrigation is applied at the right amount to reach the required level (i.e. IRRT × FC) at the end of day. Therefore, drivers such as behaviour to irrigate the irrigated area are not considered.
- The evapotranspiration factor (i.e. crop factor) changes seasonally and with different ages of the plant growth. However, a constant crop factor throughout the year is considered in the model. The model assumes the plants are at the maturity stage and not growing stage. However, since the evapotranspiration factor is a user-defined parameter, users can run the model with different values.

2.4 Default factors

Some of the required inputs can be selected from default values. The impervious fractions can be selected depending on the surface categories (see Table 5). For any surface categories that are not defined in Table **5**, users can select a general surface category and input impervious fraction as 'user-defined'. Examples could be a typical roof surface with disconnected downpipes or a roof connected to a soak well. In these examples, the impervious fraction would be less than 100% (see Table 5) depending on the percentage of roof connected to downpipe pervious surface/soak wells.

Table 5. Default impervious fractions for surface categories

Surface category	Default impervious fraction (%)[1]	Examples
Typical permeable surface	0%	Bare soil
Permeable pavement	20%	Paver categories from DesignPave / PermPave (CMMA, 2019)
Non-permeable surface	95%	Concrete Bitumen
Typical roof surface	100%	
Low level vegetation	0%	Grass
Trees	0%	Native or exotic tree varieties

[1] Derived from Water by Design (2018).

Roof surface type impacts the amount of harvestable water for rainwater harvesting and use system.

Table **6** presents roof surface runoff coefficients for a range of roof surface types.

Table 6. Default roof surface runoff coefficients for roof surface types

Roof surface type	Roof surface runoff coefficient[1]
Sloping concrete	0.9
Sloping asphalt	0.9
Sloping aluminium	0.7
Sloping metal	0.82
Sloping clay tiles	0.84
Sloping polycarbonate plastic	0.91
Sloping metal sheet	0.92
Flat bitumen	0.7
Flat gravel (low retention)	0.83
Flat gravel (high retention)	0.62
Flat cement	0.81

[1] Derived from Farreny et al. (2011)

Depending on the pervious/vegetation type, evapotranspiration can be less than (evapotranspiration factor < 1) or more than (evapotranspiration factor > 1) potential evapotranspiration. Table 7 presents default evapotranspiration factors for different pervious/vegetation types.

Table 7. Default evapotranspiration factors for different pervious/vegetation types

Pervious/vegetation type	Factor	Pervious/vegetation type	Factor
Grass	1.00	Banana	1.20
Turf grass	0.85	Palm tree	1.00
Alfalfa	0.95	Apples, Cherries, Pears	0.95
Reed	1.20	Citrus trees	0.70
Cattails	1.20	Conifer trees	1.00
Small vegetables	1.05	Trees – native varieties	1.10
Sunflower	1.10	Trees – exotic varieties	1.20
Shrubs – native varieties	1.05	Bare soil	0.30
Shrubs – exotic varieties	1.15	Open water (depth less than 2 m)	1.05
Sisal	0.70	Open water (depth more than 2 m)	0.70

Table 8 presents default values for parameters of rainfall-runoff model. The user can replace these values if a comprehensive calibration of the parameters has been undertaken for the assessed urban entity. Calibration is particularly important for urban entities that are more than 90% pervious. Most urban developments are less than 90% pervious. So, while the calibration of the rainfall–runoff model is desirable, it is not necessary for development applications due to the dominant influence of the impervious area on hydrology (Water by Design, 2018). Alternatively, the parameters can be selected depending on the soil type (see Table 9). Another alternative could be to use the results of monitoring/calibration studies. Examples include calibration of rainfall–runoff model parameters in south east Queensland (Water by Design, 2018), Perth (GHD, 2007), Melbourne (Melbourne Water, 2018), and Paddocks Catchment (Myers et al., 2015).

Table 8. Default values for rainfall–runoff parameters for major cities

Parameter	SMSC (mm)	FC (mm)	IMPSC (mm)	ISS (%)	COEFF (mm)	SQ	RFAC (%)	IRRT (%)	Impervious fraction of natural state (%)
Adelaide	40	30	1	30	200	1	25	25	1
Brisbane	120	80	1	30	200	1	25	25	1
Canberra	40	25	1	30	200	1	25	25	1
Darwin	300	250	1	30	200	1	25	25	1
Hobart	30	20	1	30	200	1	25	25	1
Melbourne	120	50	1	30	200	1	25	25	1
Perth	250	230	1	30	200	1	25	25	1
Sydney	200	170	1	30	200	1	25	25	1

Table 9. Hydrological modelling parameters (for soil types) [1]

Soil type	SMSC (mm)	FC (mm)	COEFF (mm)	SQ	RFAC (%)
sand	175	74	360	0.5	10
loamy sand	139	69	360	0.5	10
clayey sand	107	75	250	1.3	60
sandy loam	98	70	250	1.3	60
loam	97	79	250	1.3	60
silty loam	100	87	250	1.3	60
sandy clay loam	108	73	250	1.3	60
clay loam	119	99	180	3	25
clay loam, sandy	133	89	180	3	25
silty clay loam	88	70	180	3	25
sandy clay	142	94	180	3	25
silty clay	54	51	180	3	25
light clay	98	73	135	4	10
light medium clay	90	67	135	4	10
medium clay	94	70	135	4	10
medium heavy clay	94	70	135	4	10
heavy clay	90	58	135	4	10

[1] Derived from MacLeod (2008).

Occupancy rates can be selected from Census data depending on the size of dwellings presented in

Table 10. Users can use other values if local surveys are available or if they want to analyse the impacts of occupancy rates on the performance.

Dwelling type	Size	Occupancy (people per dwelling)
Detached dwelling	1 bedroom	1.6
	2 bedroom	1.9
	3 bedroom	2.5
	>3 bedroom	3.4
	Mixed	2.8
Townhouse	Studio / 1 bedroom	1.2
	2 bedroom	1.6
	3 bedroom	2.3
	>3 bedroom	3.3
	Mixed	2
Unit	Studio / 1 bedroom	1.2
	2 bedroom	1.2
	3 bedroom	2.2
	Mixed	1.7

Dwelling type	Size	Occupancy (people per dwelling)
Detached dwelling	1 bedroom	1.6
	2 bedroom	1.9
	3 bedroom	2.5
	>3 bedroom	3.4
	Mixed	2.8
Townhouse	Studio / 1 bedroom	1.2
	2 bedroom	1.6
	3 bedroom	2.3
	>3 bedroom	3.3
	Mixed	2
Unit	Studio / 1 bedroom	1.2
	2 bedroom	1.2
	3 bedroom	2.2

	Mixed	1.7

Table 10. Residential occupancy rates

Water by Design (2018), citing ABS census data from the 2006 Census of Population and Housing.

Daily precipitation and daily potential evapotranspiration time series, and soil characteristics for major Australian cities are saved in SUWMBA data libraries for a rapid analysis of water performance in different locations.

Table **11** presents a summary of the data libraries. Users can use ‘user-defined’ options to add local data for locations and years that are not covered in

Table **11**. Alternatively, users can contact the development team for updating data libraries for their specific needs.

Table 11. Data libraries

Data	Region	Year	Source
Precipitation (daily)	Adelaide (023090) Bendigo (081123) Brisbane (40913) Cairns (031011) Darwin (014015) Essendon Airport (86038) Fremantle (09192) Goulburn (TAFE) (70263) Hobart (94029) Lithgow (Cooerwull) (63226) Melbourne (086232) Orange (063303) Perth (009225) Perth Airport (09021) Sydney (066062) Townsville (032040) Singapore (Nicoll Highway) User-defined	FY2001 – FY2019	Australian Climate Data Online (Bureau of Meteorology, 2018b)
Potential evapotranspiration (daily)	Adelaide Bendigo Brisbane Brisbane River Cairns Darwin Goulburn (NSW, 2580) Hobart Lithgow (NSW, 2790) Maribyrnong River Melbourne Orange Perth Swan Coast Sydney Torrens River Townsville User-defined	FY2005 – FY2019	Australian Landscape Water Balance (Bureau of Meteorology, 2018a)
Soil characteristics	Adelaide Brisbane Canberra Darwin Hobart Melbourne Perth Sydney	N/A	MUSIC model documentation (eWater, 2017) See Table 8.

2.5 Model assumptions and cautions

The main assumptions of the SUWMBA Tool are summarised below.

- All zones in the site have uniform soil with characteristics defined by the user by either selecting default values or entering user-defined values. However, if this is not the case for the urban entity assessed, users can break down the entity into smaller units with uniform soil and run the tool for each unit separately.
- Only one rainwater tank is assumed. For cases with multiple rainwater tanks, users can either aggregate the roof areas and rainwater tanks or break down the entity and run the tool for each sub-unit. For example, to model four rainwater tanks of 1,000 L, users can either run SUWMBA once with aggregated roof areas connected to a rainwater tank of 4,000 L (4×1,000 L), or run the tool four times, once for each rainwater tank and connected roof area. The different approach is insignificant for uniform (uniform roof area, tank size, soil characteristics, etc.) and small urban entities (up to 4 ha) thus the first approach is suggested.
- The reliability of purple pipe and water mains connections is 100% meaning that water demand is completely met either by internal harvest (i.e. harvested rainwater) or by water mains and purple pipe.
- Purple pipe meets only irrigation demand.
- The water demand model uses south east Queensland samples and assumes the relationships between the influencing factors and household water demand are valid for the rest of Australia.
- There are no hydrological interactions between zones, meaning stormwater runoff from one zone does not flow to another zone. Therefore, the tool should be used cautiously for large urban entities (~ 50 ha if no rainwater tank is assumed).
- The daily rainfall–runoff model does not account for snow accumulation. Therefore, the tool’s usefulness in cold climates with significant snowmelt contribution to stormwater discharge is limited.
- Up to 20 zones and up to 10 alternative scenarios can be assessed and compared at a time. Users can copy the result sheet to an external excel sheet to compare more than 10 scenarios.

3. Instructions for running the SUWMBA Tool

When you open the Excel file, you may receive a warning that 'macros have been disabled' (see Figure 3). If this occurs, click 'Enable Content' to allow the tool to function.

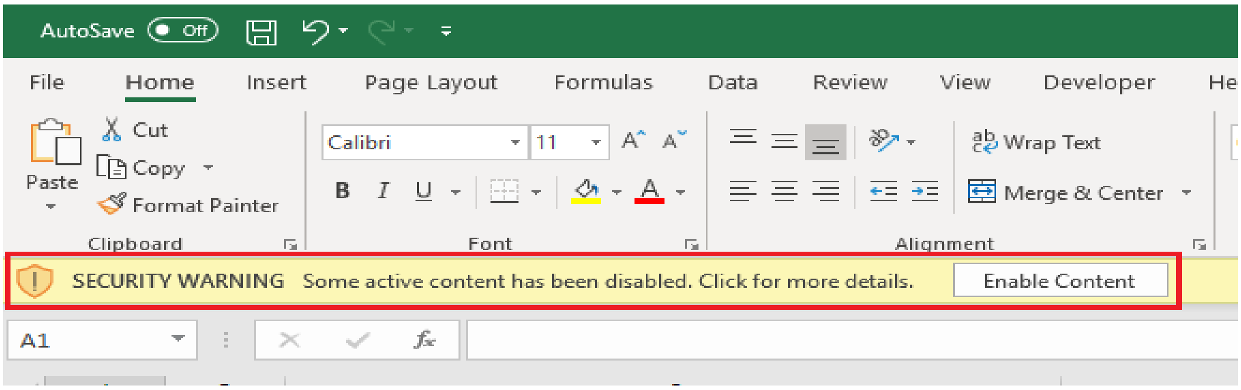


Figure 3. Click 'Enable Content' to allow the tool to function

Step 1: Define the urban area to be assessed

The 'urban area' should include all areas of the development, including any changes to the land cover or population. The boundary of the proposed development site, proposed road or allotment layout could be used as a starting point to decide the urban entity system boundary. Then the entity can be divided to sub-units if some areas are non-uniform (e.g. the entity has both low-density and medium-density residential areas, or the soil characteristics are different across the site). The borders of the urban entity (or sub-units) must be explicitly defined, and then land covers within the borders, as well as other inputs, are measured (see section 0 for the list of inputs). Then the tool can be used to quantify the performance of the defined entity (or sub-units). Figure 4 provides an example of an urban entity and its boundary.

Step 2: Input data to estimate urban water flows

All inputs are defined in the 'INPUT – Site' worksheet (see **Error! Reference source not found.**). Start by describing the site and the environmental context (in fields 1 and 2). Defining the environmental context involves selecting the region and the year so the tool knows which rainfall, potential evapotranspiration (PET) and soil dataset to use.

There are two buttons to check the rainfall and PET data:

Click 'Check rainfall data' to get annual precipitation and to check if any data is missing for the selected rainfall station and year.

Click 'Check PET data' to get annual evapotranspiration and to check if any data is missing data for the selected PET catchment and year.

Next, define each component zone present on the site (in field 3), by listing a 'Descriptor', categorising the 'Surface category', and entering the 'Area of zones'. A default imperviousness factor will be generated based on the entered surface type. Alternatively, you can insert another value in the adjacent column.

Then, you can indicate if rainwater is harvested from any of the zones (in field 4), and if any of the zones are irrigated (in field 5A).

If any zones are partly pervious, you can indicate the pervious type (whether it is vegetated or bare soil) and whether the vegetated areas are irrigated (in field 5A).

You can use either the lumped approach or the split approach to define inputs. The **lumped approach** combines areas with the same surface category (e.g. roof areas of all buildings are lumped together). This approach is suitable for broad scale master planning, conceptual planning, and development planning where detail performance is not required.

By contrast, the **split approach** treats each surface category separately (e.g. roof areas of each building are entered as different zones). This approach is suitable for urban design, comparing alternatives (e.g. alternative connection of roof areas to rainwater tanks), small scale and detailed analysis, and highly non-uniform urban entities. Figure 4 presents an example of the lumped and split approaches for the same site.

Next, enter details to allow the tool to estimate water demand and use, including:

the number of people, their age composition (i.e. the number of adults, teenagers, children 4–12 years of age, and children 0–3 years of age), and the annual income of the household in Australian dollars

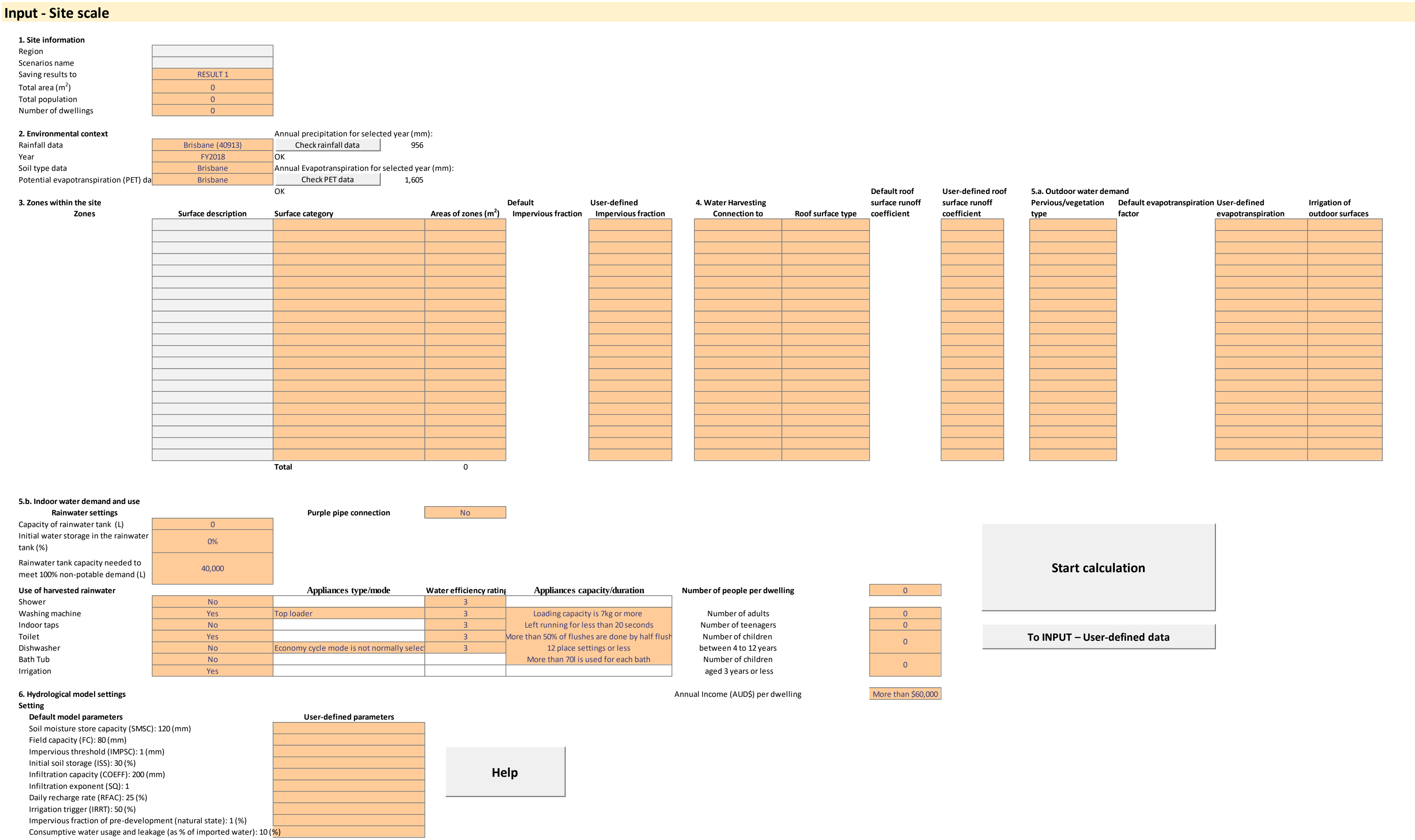
appliance types, modes, capacity, and water efficiency rating. Appliance type/mode refers to the type of washing machine (top versus front load) and dishwasher (ECO mode availability). Capacity/duration refers to the capacity of the washing machine, the duration of tap usage, frequency of half-flushes, capacity of dishwasher and bath tub. Water ratings refer to the Australian Water Efficiency Labelling and Standards (WELS)[1] scheme.

if rainwater is used for each appliance and irrigation. If rainwater is used, enter the rainwater tank size in m^3. Rainwater tanks less than 2 m^3 in volume are small; tanks 2–10 m^3 in volume are medium. If you don't select rainwater use or purple pipe use, the tool assumes potable water is used for these uses, and any irrigation demand selected in Section 5A.

Depending on the soil type data selected in the environmental context field (field 2), the tool selects a set of default values for rainfall–runoff parameters in the 'hydrological model settings' (field 6). You can change the default parameters by entering alternative values in the 'user-defined parameters' in field 6.

If you select 'user-defined' for precipitation and evapotranspiration, you can provide data by clicking the 'To INPUT – User-defined data' button to open the user-defined data input spreadsheet (Figure 5). In the input interface, you can input the corresponding data. Once completed, click the 'Close and return' button to return to the main input spreadsheets.

[1] http://www.waterrating.gov.au/



Input - Site scale

1. Site information

Region	
Scenarios name	
Saving results to	RESULT 1
Total area (m^2)	0
Total population	0
Number of dwellings	0

2. Environmental context

		Annual precipitation for selected year (mm):	
Rainfall data	Brisbane (40913)	Check rainfall data	956
Year	FY2018	OK	
Soil type data	Brisbane	Annual Evapotranspiration for selected year (mm):	
Potential evapotranspiration (PET) da	Brisbane	Check PET data	1,605
		OK	

3. Zones within the site Zones	Surface description	Surface category	Areas of zones (m^2)	Default Impervious fraction	User-defined Impervious fraction	4. Water Harvesting Connection to	Roof surface type	Default roof surface runoff coefficient	User-defined roof surface runoff coefficient	5.a. Outdoor water demand Pervious/vegetation type	Default evapotranspiration factor	User-defined evapotranspiration	Irrigation of outdoor surfaces
		Total	0										

5.b. Indoor water demand and use

Rainwater settings

Capacity of rainwater tank (L)	0	**Purple pipe connection**	No
Initial water storage in the rainwater tank (%)	0%		
Rainwater tank capacity needed to meet 100% non-potable demand (L)	40,000		

Use of harvested rainwater		**Appliances type/mode**	**Water efficiency rating**	**Appliances capacity/duration**
Shower	No		3	
Washing machine	Yes	Top loader	3	Loading capacity is 7kg or more
Indoor taps	No		3	Left running for less than 20 seconds
Toilet	Yes		3	More than 50% of flushes are done by half flush
Dishwasher	No	Economy cycle mode is not normally selec	3	12 place settings or less
Bath Tub	No			More than 70l is used for each bath
Irrigation	Yes			

Number of people per dwelling	0
Number of adults	0
Number of teenagers	0
Number of children between 4 to 12 years	0
Number of children aged 3 years or less	0
Annual Income (AUD$) per dwelling	More than $60,000

Start calculation

To INPUT – User-defined data

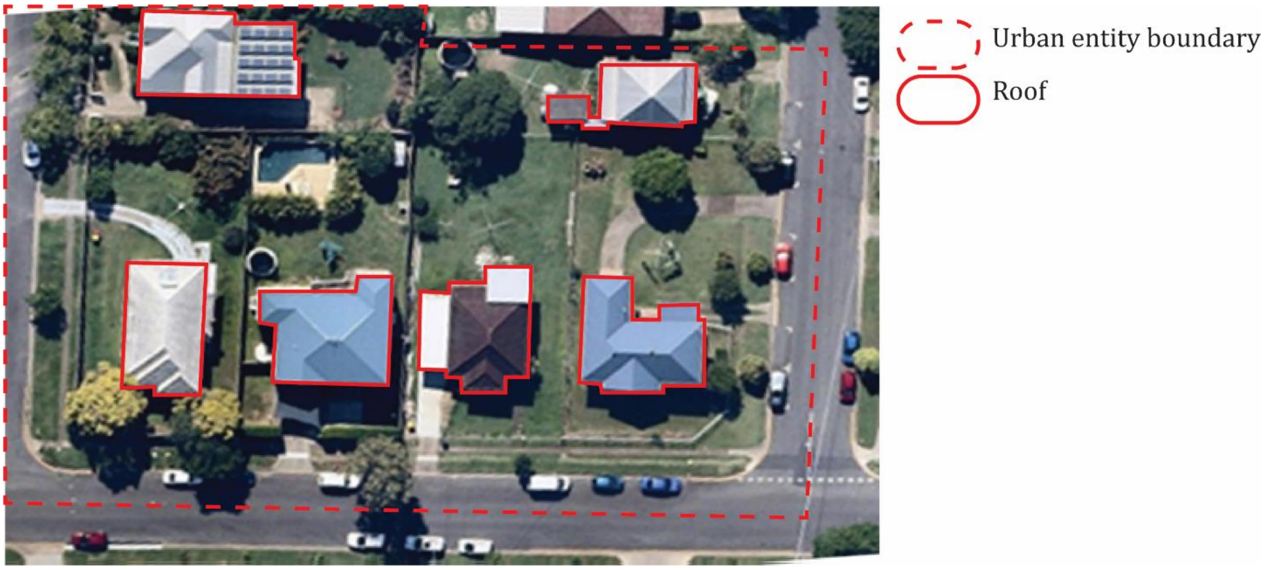
6. Hydrological model settings

Setting

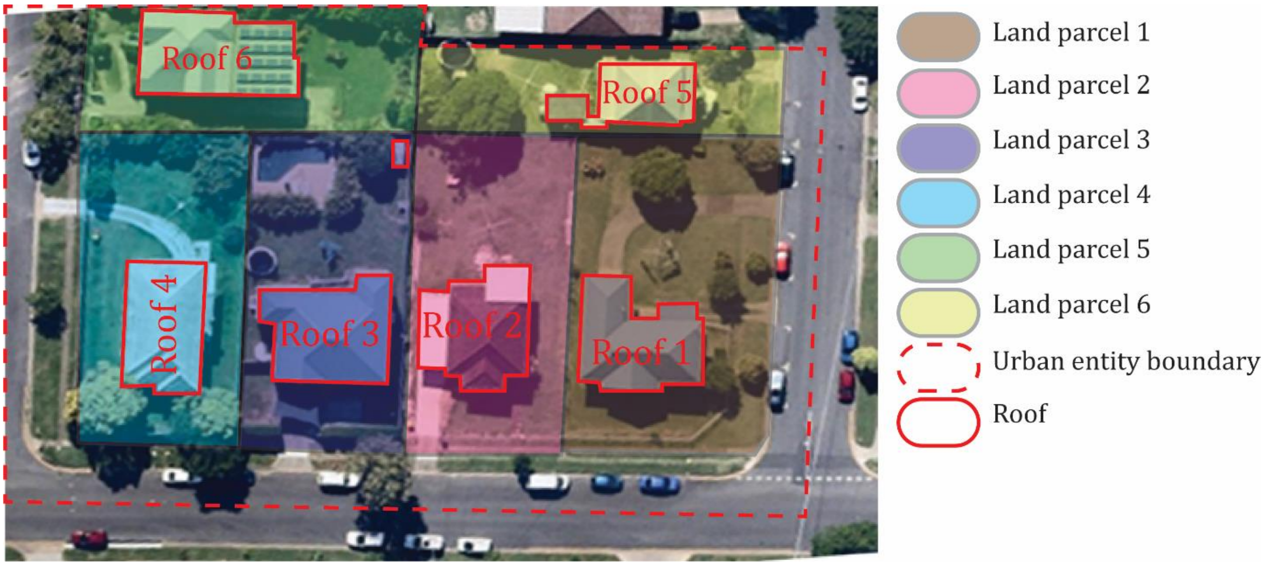
Default model parameters	**User-defined parameters**
Soil moisture store capacity (SMSC): 120 (mm)	
Field capacity (FC): 80 (mm)	
Impervious threshold (IMPSC): 1 (mm)	
Initial soil storage (ISS): 30 (%)	
Infiltration capacity (COEFF): 200 (mm)	
Infiltration exponent (SQ): 1	
Daily recharge rate (RFAC): 25 (%)	
Irrigation trigger (IRRT): 50 (%)	
Impervious fraction of pre-development (natural state): 1 (%)	
Consumptive water usage and leakage (as % of imported water): 10 (%)	

Help

Figure 4. 'INPUT – Site' worksheet



A: Lumped approach



B: Split approach

Figure 4. An example for defining urban entity and input data.

Figure 5A shows the lumped approach, which groups all roof areas within the urban entity together. Figure 5B shows the split approach, which divides the urban entity into six sub-units based on the land parcels.

For simplicity, Figure 5B shows only one surface category (i.e. roof). Under this approach, other surface categories (e.g. pavement, road, trees, grass, etc.) must also be defined. Each sub-unit is modelled separately and the performance of the assessed urban entity is derived by aggregating the performance of each sub-unit.

The division criteria could be based on other characteristics such as soil characteristics or land use depending on the objective of the analysis (this example uses land parcels).

INPUT – User-defined data

◄◄Close and return to INPUT - Site

Rainfall

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th
Jul	0.2	13.8	0	0	0	0	0	0	0	0	0.4	0	0	0	1.4
Aug	0	1.6	0	0	0	0	0	0	8.4	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0	0	0	0	0	6.4	0	0
Oct	2.2	0.2	0	0.6	0.8	4.6	3.4	0	0	0	0	0.6	0	0	3.4
Nov	2.2	0	8	0	0.4	1.8	27.8	3.2	2.4	3	0	0	0	0	0
Dec	8.8	1.8	0	0.2	0	0	0	0	0	0	0.4	0	0	0	0
Jan	2.4	8.4	0	0	0	0.6	0	2.2	0	0	5.4	1	0	0.4	0.8
Feb	0	0	0	0.4	0	0	0	0	0	0	0	0	0	0	0.6
Mar	0	0	7	0.2	0	11	0.6	0	5.4	0	0	0	0	0	0
Apr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0.6	0.4	0	0	0	0	0	0	0	0	14.4	0.4	0	0.4
Jun	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	1.4

	16th	17th	18th	19th	20th	21st	22nd	23rd	24th	25th	26th	27th	28th	29th	30th	31st
Jul	1.6	0	0	0	0	0.2	0	0	0	0	0	0	0.8	4	0	0
Aug	0	0	0	0	0	0	0	0	2.8	2.8	0	0	0	0	0	0
Sep	0.4	0	0	0	0	0	0	0	0	0	0	13.4	0	0	0	
Oct	0	0	16.6	1.6	4.6	3.2	0	0	0	0	0	0	6.2	1.8	2.6	0
Nov	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Dec	0	0	0	0	0	0	0	0	0.6	0	0	0	0	0	0.6	0
Jan	3.2	5.6	0	0	0	0	0	0.6	0	0	0	0	0	1.4	0.6	3.4
Feb	0	2.8	2.6	0	0	0	2.2	0.2	2.4	0.2	0	0	0	0		
Mar	0	0	0	0	1.2	0	0	0	7.2	0	0	0	0	0	0	0
Apr	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	
May	0.4	0	0	0	0	0	1.4	0	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	9.6	0.2	0	0	0	0	0	0	5.2	

Potential evapotranspiration

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th
Jul	1.61	1.01	1.51	1.27	1.61	1.23	1.72	1.95	1.51	1.65	1.03	1.73	1.48	0.86	1.41
Aug	1.42	1.87	1.29	1.81	1.55	1.92	1.67	1.45	1.64	2.12	2	1.67	1.82	1.98	2
Sep	3.1	2.86	1.89	2.56	2.51	2.74	2.14	2.3	2.42	2.62	3.78	3.3	4.32	4.52	2.74
Oct	4.94	5.59	5.99	5.87	6.58	6.71	4.14	5.18	5.64	5.33	4.7	2.66	5.09	6.33	6.76
Nov	3.86	2.59	5.41	5.54	4.36	2.71	5.03	6.54	7.93	1.78	4.67	6	4.56	4.95	5.76
Dec	6.17	5.98	7.21	8.39	7.67	5.87	3.76	7.81	7.45	7.32	4.73	6.31	7.7	7.85	7.67
Jan	5.61	6.86	5.28	4.17	5.1	5.28	6.24	6.95	7.18	8.65	6.91	7.94	9.5	1.83	4.54
Feb	7.09	7.1	2.86	4.18	7.58	7.91	7.28	6.02	7.01	6.37	6.54	7.1	6.82	6.04	6.47
Mar	6.85	7.1	5.37	6.79	4.84	6.22	3.82	7.42	4.25	1.81	4.75	3.24	4.63	3.12	5.42
Apr	4.28	2.77	3.51	4.26	4.81	1.05	3.25	3.17	3.69	3.6	2.89	2.68	3.07	4.17	4.36
May	1.63	2.66	2.44	2.51	2.71	3.25	3.44	1.71	1.99	1.67	1.82	2.4	2.31	2.61	2.43
Jun	2.24	1.93	1.75	1.39	1.3	1.58	1.45	1.37	1.63	1.58	1.42	1.77	1.72	1.78	2.02

	16th	17th	18th	19th	20th	21st	22nd	23rd	24th	25th	26th	27th	28th	29th	30th	31st
Jul	1.61	1.46	1.47	1.98	2.12	2.2	1.52	2.12	1.77	1.44	1.26	1.81	1.89	1.72	1.43	2.02
Aug	2.65	1.63	1.74	2.22	2.7	2.37	2.83	2.69	2.06	1.72	2.31	1.39	2.09	2.07	1.92	2.31
Sep	2.95	2.57	2.44	4.03	4.36	2.62	2.56	3.11	3.27	4.05	4.27	4.4	4.27	3.67	3.27	
Oct	2.99	5.04	5.08	6.5	5.66	2.04	2.62	4.4	5.74	6.47	3.01	6.12	6.59	6.6	6.6	4.47
Nov	7.22	7.56	7.75	7.1	3.18	5.25	6.39	5.62	7.36	7.2	4.93	4.3	6.65	4.64	7.77	
Dec	8.27	9.31	9.11	9.01	6.3	5.44	7.3	7.53	8.75	8.97	4.38	5.39	7.73	8.32	9.27	9.16
Jan	7.52	8.34	8.88	8.23	5.75	5.16	2.65	3.92	4.3	5.85	7.57	5.78	5.13	3.18	5.49	3.07
Feb	3.69	4.29	4.48	4.07	5.35	6.69	4.93	7.55	5.15	5.39	5.24	5.07	5.44	5.25		
Mar	5.95	5.96	2.83	2.96	4.84	4.86	5.33	4.93	2.38	3.61	2.91	3.2	3.16	2.81	2.62	4.23
Apr	2.72	2.85	3.98	4.1	4.09	2.12	1.82	2.48	3.41	3.84	3.87	3.24	2.53	1.39	2.56	
May	2.68	1.88	2.06	1.65	1.99	2.35	2.78	1.52	1.83	2.01	1.02	1.82	1.83	1.47	1.82	2.27
Jun	1.79	1.52	0.91	1.49	1.3	1.23	1.39	1.19	1.01	1.61	1.41	1.36	1.71	1.6	0.8	

Figure 5. User-defined data input interface

Step 3: Generate results

Once all inputs are defined, click the 'Start calculation' button. Within a few seconds, the result sheet will display (Figure 7). If the 'Incomplete inputs' error occurs, check the following :

- Check 'Pervious/vegetation type' and 'Irrigation of outdoor surface' are entered for all zones with a pervious fraction and there is no red 'Check' warning in column M.
- Check 'Roof surface type' is selected if one or more zones are connected to a rainwater tank and there is no '#N/A' warning in column K.
- Check the summation of 'Areas of zones' matches 'Total area' entered in cell C7 and there is no red 'Check the numbers with the total area' warning in cell E41.
- Check 'Total population' matches 'Number of people per dwelling' and 'Number of dwellings' and there is no red 'Check total population, number of dwellings, and number of people per dwelling' warning in cell K59.
- Check the age composition of household is complete and there is no red 'Check the numbers' warnings in cell K56.

Once the tool has generated the results sheet, do not change the name of the RESULTS tab.

Annual urban water mass balance

The first section of the results is the water mass balance for the urban entity assessed. Inflows and outflows are separated and presented in ML/year and mm/yr. A schematic representation of urban entity and inflows and outflows is provided on the right-hand side of the urban water mass balance flows.

Performance indicators

If an error '#DIV/0!' is generated for hydrological performance – runoff indicators, the pre-developed runoff is zero.

Input settings

A summary of input settings provides a rapid check of the results against inputs.

Step 4: Analyse scenarios

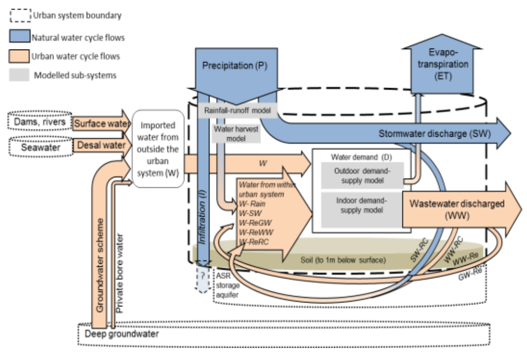
In most cases, users will be interested to explore how the water mass balance and the performance indicators may change under different conditions. Repeat steps 2 to 4 to define and run different scenarios. For each scenario, you can save the results to different result sheets (selecting from cell C6 in 'INPUT – Site' sheet) and name the scenarios (in cell C5 in 'INPUT – Site' sheet).

Result – Site scale 1 Annual A

◄◄ Close and return to the INPUT – Site sheet

Annual Urban Water Mass Balance

		ML/yr	ML/yr	mm/yr
Inflows	Precipitation (P), less harvested rainwater	0.10		960
	Imported water from outside the urban system (W)	0.12		1,160
	Surface water supply (from dams and rivers)	0		
	Desalinated water supply (from sea water)	0		
	Groundwater supply (from scheme)	0		
	Groundwater supply (from private bore)	0		
	Water sourced from the urban system	0.00		0
	Recycled wastewater or greywater supply (W-ReWW)	0		
	Reused groundwater supply (W-ReG) from recharged aquifer	0		
	Water sourced from the study area	0.00		0
	Rainwater supply (W-Rain) from roof runoff	0		
	Rainwater supply (W-SW) from surface runoff	0		
	Recycled wastewater or greywater supply (W-ReWW)	0		
	Reused groundwater supply (W-ReGW) from recharged aquifer	0		
	TOTAL INFLOWS	**0.21**		2,120
Outflows	Evapotranspiration (ET)	0.01		90
	Stormwater discharge (SW) to surface water	0.10		980
	Stormwater recharged (SW-RC) to shallow groundwater	0.00		0
	Infiltration (I) through soil to shallow groundwater	0.00		0
	Wastewater discharged to surface waters (WW)	0.11		1,050
	Wastewater recharged to shallow groundwater (WW-RC)	0.00		0
	Wastewater or greywater recycled to the urban system (WW-Re or GW-R	0.00		0
	TOTAL OUTFLOWS	**0.21**		2,120
				0
	Change in soil moisture storage	0.00		0
	Change in stored water	0.00		0
	Change in shallow groundwater stores	0.00		0



Performance indicator

		Value	Unit
Mid-point indicators	Site's built area fraction	100	%
	Site's vegetated area fraction	0	%
	Permeable fraction of hard surfaces	0	%
	Site's overall impervious fraction	100	%
	Vegetated fraction irrigated	#DIV/0!	%
	Indoor water demand per capita	159	L/person/day
	Outdoor water demand per capita	0	L/person/day
	Extent of wastewater recycling	0	%
	Volume of on-site constructed water storage, relative to optimal storage	0	%
	Self-sufficiency (% of water demand met by water sourced from within the urban system)	0.0	%
	Water storage capacity (in soil), for supporting vegetation and cooling	0.00	kL
	Total water storage capacity, for reducing stormwater discharge	0.10	kL
	Water storage capacity (in reservoirs), for harvesting - effective volume	0.00	kL
End-point indicators	Fraction of rainfall that converts to stormwater discharge	102	%
	Naturalness of stormwater discharge	942	%
	Number of stormwater discharge events	82	days
	Peak daily stormwater discharge	0.01	ML
	Fraction of rainfall that infiltrates	0	%
	Naturalness of infiltration	0	%
	Fraction of rainfall that recharges to shallow aquifer)	0	%
	Aquifer storage recharge: reuse ratio	#DIV/0!	%
	Fraction of rainfall that evapotranspires	10	%
	Naturalness of evapotranspiration	12	%
	Per capita use of imported water	159	L/person/day
	Reliance on imported water	100	%
	Number of stormwater discharge events in reference case	21	days
	Peak daily stormwater discharge in reference case	0.01	ML
	Volumetric reliability of rainwater tank	0.0	%
	Volume of soil moisture storage capacity, relative to natural state	1	%

Input setting

1. Site information

Region	
Scenarios name	
Saving results to	RESULT 1
Total area (m2)	0
Total population	0
Number of dwellings	z

Figure 6. Result sheet interface

Note: ‘input setting’ is not completely shown here because it is the same as the ‘Input – site’ worksheet.

4. SUWMBA Tool tutorial

This section is a 'hands-on' introduction to the SUWMBA Tool, to demonstrate how to use the tool. The tutorial is based on a development site in Brisbane (Site A).

Site A is a small site that consists of six detached houses and surrounding roads (Figure 4). It accommodates 18 residents. We use a lumped approach to define surface categories, presented in Table 12.

Table 12. Surface categories of Site A

Surface categories	Area (m^2)	Percentage (%)
Roof	360	22
Road	220	13
Paved	220	13
Grass	750	52
Trees	100	
Total	**1,650**	

Open SUWMBA.xlsx. Read the condition of use statement and if you agree click on 'Enable content' (only for the first time; see Section 0 for more detail) then click on 'Start'. The 'INPUT – Site' worksheet will open.

In section '**1. Site information**', input general information such as site area and population as shown below.

Region	**Site A**
Scenarios name	**Base case**
Saving results to	RESULT 1
Total area (m^2)	1,650
Total population	18
Number of dwellings	6

In section '**2. Environmental context**' select Brisbane for rainfall data, soil type, and potential evapotranspiration (PET). Select FY2018 for the year and check both annual precipitation and annual PET. The tool checks the precipitation and PET database then returns a message if the database is complete ('OK') or if data is missing ('Missing data').

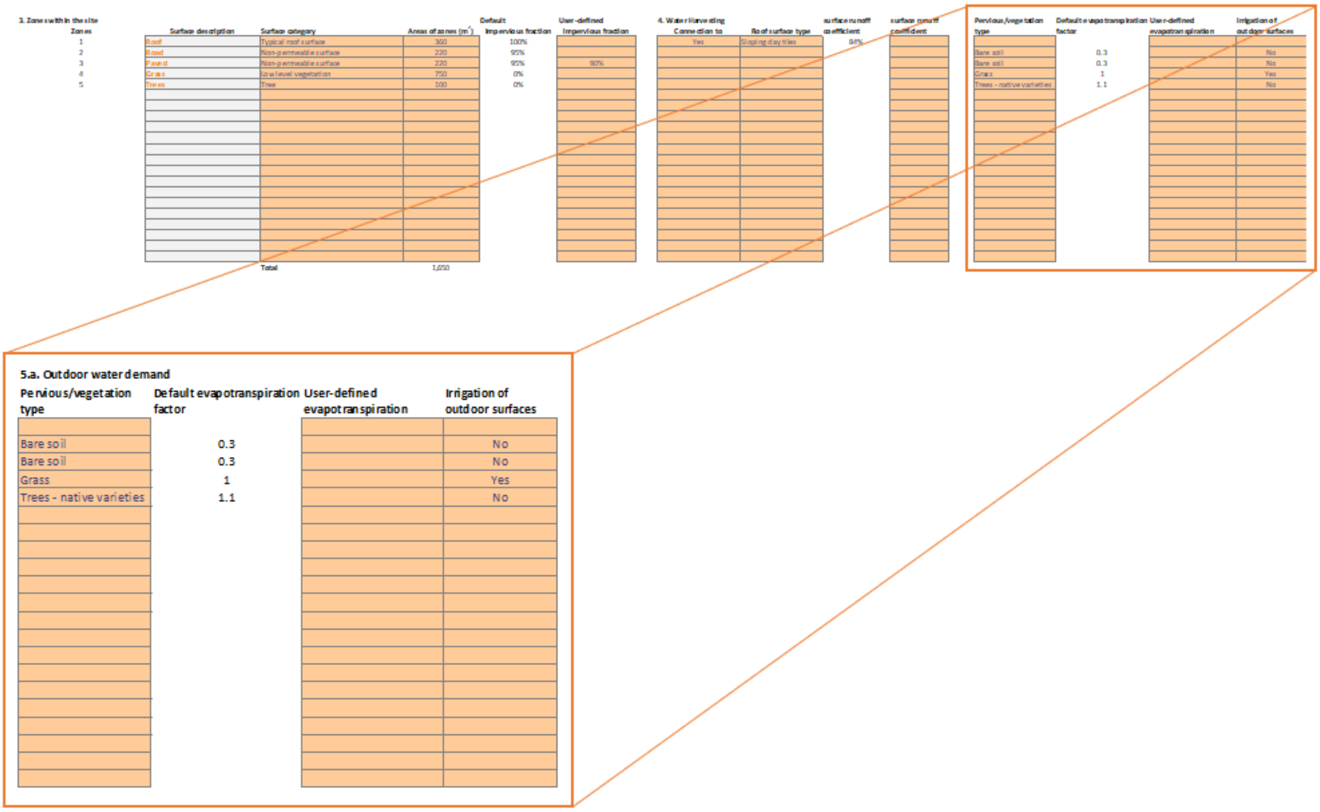
In Section ‘**3. Zones within the site**’, enter the surface categories information as follows. Change the impervious fraction of paved areas to 90% as shown below.

3. Zones within the site

Zones	Surface description	Surface category	Areas of zones (m^2)	Default Impervious fraction	User-defined Impervious fraction
1	Roof	Typical roof surface	360	100%	
2	Road	Non-permeable surface	220	95%	
3	Paved	Non-permeable surface	220	95%	90%
4	Grass	Low level vegetation	750	0%	
5	Trees	Tree	100	0%	
		Total	1,650		

In section ‘**4. Water Harvesting**’, select ‘Yes’ for the first zone (i.e. the zone that corresponds to roof areas, see the above figure). And assume ‘Sloping clay tiles’ for ‘Roof surface type’.

In section ‘**5.a. Outdoor water demand**’, select ‘Bare soil’ for Road and Paved areas, ‘Grass’ for grass areas, and ‘Trees – native varieties’ for tree areas as shown below. Assume only grass areas are irrigated.



In section **'5.b. Indoor water demand and use'**, assume:

- 'Capacity of rainwater tank' is 6,000 L which corresponds to six rainwater tanks of 1,000 L (one for each dwelling)
- the rainwater tank is empty at the beginning of the calculations and the required capacity to meet 100% of non-potable use is 40,000 L as shown below
- harvested rainwater is used for 'Washing machine', 'Toilet' and 'Irrigation'
- appliances and water fixtures with low efficiency are as shown below
- a purple pipe connection is not considered.

5.b. Indoor water demand and use

Rainwater settings		**Purple pipe connection**	No
Capacity of rainwater tank (L)	6,000		
Initial water storage in the rainwater tank (%)	0%		
Rainwater tank capacity needed to meet 100% non-potable demand (L)	40,000		

Use of harvested rainwater		**Appliances type/mode**	**Water efficiency rating**	**Appliances capacity/duration**
Shower	No		3	
Washing machine	Yes	Top loader	3	Loading capacity is 7kg or more
Indoor taps	No		3	Left running for less than 20 seconds
Toilet	Yes		3	More than 50% of flushes are done by half flush
Dishwasher	No	Economy cycle mode is not normally select	3	12 place settings or less
Bath Tub	No			More than 70l is used for each bath
Irrigation	Yes			

In '**Number of people per dwelling**', input the dwelling demographic composition, assuming:

- a typical Australian family of three family members with two adults and one teenager
- the annual income of the households is more than $60,000 on average.

The last section '**6. Hydrological model settings'** summarises the parameters used for hydrological modelling, using the default values in this case. However, user-defined parameters can be used.

Click on 'Start calculation' to see the result in the 'RESULT 1 – Site scale' sheet.

The results of the annual urban water mass balance are presented below.

Result – Site scale 1 Annual Base case

Annual Urban Water Mass Balance

		ML/yr	ML/yr	mm/yr
Inflows	Precipitation (P), less harvested rainwater	1.40		848
	Imported water from outside the urban system (W)	1.16		704
	Surface water supply (from dams and rivers)		0	
	Desalinated water supply (from sea water)		0	
	Groundwater supply (from scheme)		0	
	Groundwater supply (from private bore)		0	
	Water sourced from the urban system	0.00		0
	Recycled wastewater or greywater supply (W-ReWW)		0	
	Reused groundwater supply (W-ReG) from recharged aquifer		0	
	Water sourced from the study area	0.18		107
	Rainwater supply (W-Rain) from roof runoff		0.177	
	Rainwater supply (W-SW) from surface runoff		0	
	Recycled wastewater or greywater supply (W-ReWW)		0	
	Reused groundwater supply (W-ReGW) from recharged aquifer		0	
	TOTAL INFLOWS	**2.74**		1,659
Outflows	Evapotranspiration (ET)	1.14		692
	Stormwater discharge (SW) to surface water	0.64		387
	Stormwater recharged (SW-RC) to shallow groundwater	0.00		0
	Infiltration (I) through soil to shallow groundwater	0.09		54
	Wastewater discharged to surface waters (WW)	0.87		527
	Wastewater recharged to shallow groundwater (WW-RC)	0.00		0
	Wastewater or greywater recycled to the urban system (WW-Re or GW-Re)	0.00		0
	TOTAL OUTFLOWS	**2.74**		1,660
				0
	Change in soil moisture storage	0.00		-1
	Change in stored water	0.00		-1
	Change in shallow groundwater stores	0.09		54

The results show the urban entity imported 1.16 ML of water in 2018. An additional 0.18 ML of water was sourced through rainwater harvesting system and 1.40 ML through precipitation which gives a total inflow of 2.74 ML. This volume leaves the system as evapotranspiration (1.14 ML), stormwater (0.64 ML), infiltration (0.09 ML), and wastewater (0.87 ML) which give total outflow of 2.74 ML.

The water performance of the assessed urban entity is presented below:

- The overall imperviousness of the site is 46% and 88% of vegetation is irrigated.
- On average each person uses 147 L for indoor uses and 57 L for outdoor uses.
- The current rainwater tank size corresponds to 15% of the required capacity to meet 100% of non-potable water (i.e. 6,000 L / 40,000 L) which provided self-sufficiency of 13.2% and volumetric reliability of 23.3%.
- Total storage, soil storage, and built storage are 112.73, 105.96, and 6 KL, respectively.
- The fraction of rainfall that converts to stormwater, infiltration, and evapotranspiration is 41%, 6%, and 72%, respectively. The sum is greater than 100%, indicating the contribution of imported water through irrigation.

The current urban entity has increased stormwater flow compared with pre-development (i.e. natural hydrology) to 373%. However, infiltration and evapotranspiration have reduced to 73% and 89% respectively of flows in pre-development (naturalness ratios). Stormwater discharge events increased by 290%, from 21 days pre-development to 82 days. Peak daily stormwater discharge increased 55% from 0.09 ML/day to 0.14 ML/day. Reliance on imported water is 87%. Soil moisture is 54% of the soil moisture capacity in pre-development case.

		Value	Unit
Mid-point indicators	Site's built area fraction	48	%
	Site's vegetated area fraction	52	%
	Permeable fraction of hard surfaces	4	%
	Site's overall impervious fraction	46	%
	Vegetated fraction irrigated	88	%
	Indoor water demand per capita	147	L/person/day
	Outdoor water demand per capita	57	L/person/day
	Extent of wastewater recycling	0	%
	Volume of on-site constructed water storage, relative to optimal storage	15	%
	Self-sufficiency (% of water demand met by water sourced from within the urban system)	13.2	%
	Water storage capacity (in soil), for supporting vegetation and cooling	105.96	kL
	Total water storage capacity, for reducing stormwater discharge	112.73	kL
	Water storage capacity (in reservoirs), for harvesting - effective volume	6.00	kL
End-point indicators	Fraction of rainfall that converts to stormwater discharge	41	%
	Naturalness of stormwater discharge	373	%
	Number of stormwater discharge events	82	days
	Peak daily stormwater discharge	0.14	ML
	Fraction of rainfall that infiltrates	6	%
	Naturalness of infiltration	73	%
	Fraction of rainfall that recharges to shallow aquifer)	5	%
	Aquifer storage recharge: reuse ratio	0	%
	Fraction of rainfall that evapotranspires	72	%
	Naturalness of evapotranspiration	89	%
	Per capita use of imported water	177	L/person/day
	Reliance on imported water	87	%
	Number of stormwater discharge events in reference case	21	days
	Peak daily stormwater discharge in reference case	0.09	ML
	Volumetric reliability of rainwater tank	23.3	%
	Volume of soil moisture storage capacity, relative to natural state	54	%

5. Technical details

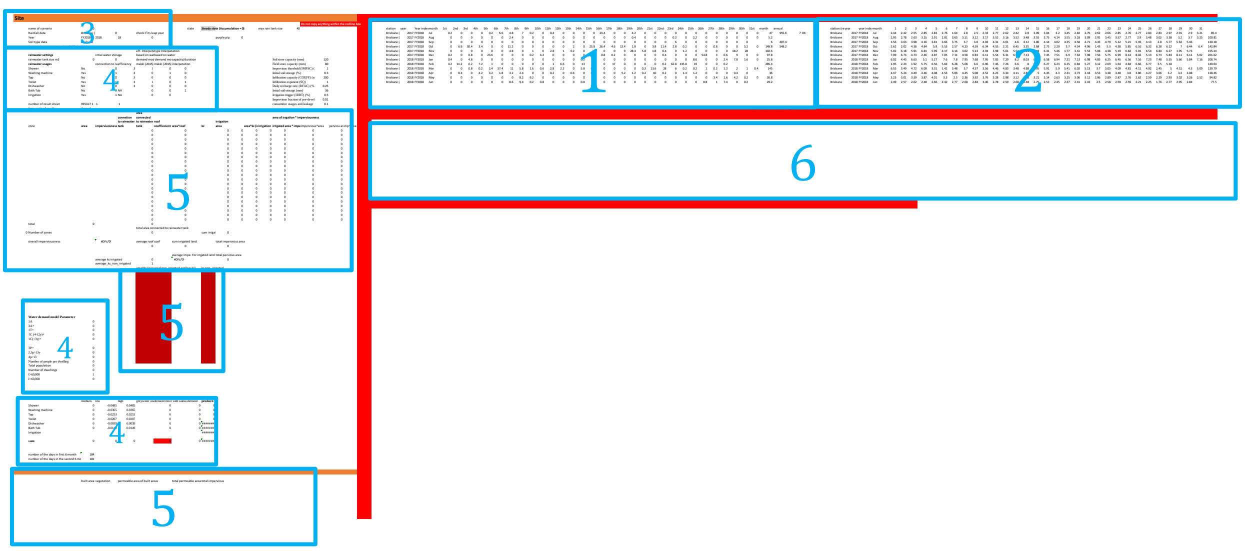
This section explains the hidden sheets in the tool. Moravej et al. (in prep.) provides details about the models used in the tool.

Hidden sheets can be seen by right clicking on sheet tabs and selecting 'Unhide…'. You can select and make visible the following sheets:

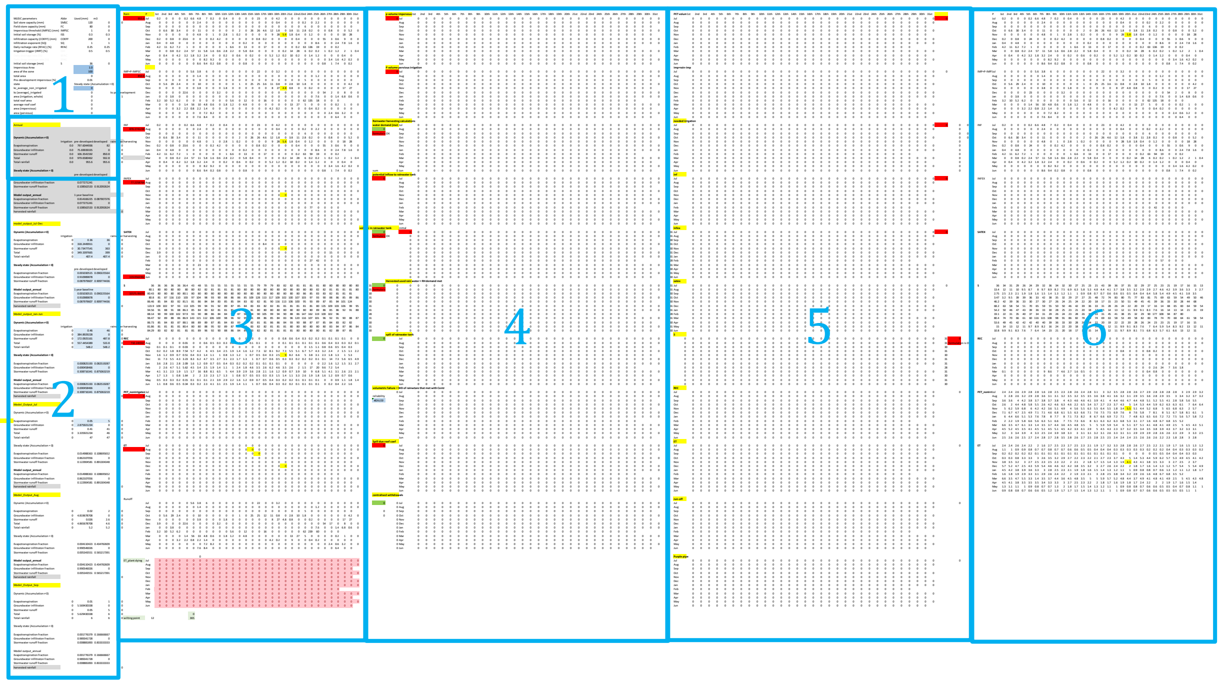
- MODEL – Input summary – Site
- MODEL – MUSIC – Site
- CALCULATION – Site
- LIBRARY – Rainfall
- LIBRARY – PET
- Version log.

'MODEL – Input summary – Site' summarises all the inputs including parameters, zones, settings, and rainfall and potential evapotranspiration data obtained from **LIBRARY – Rainfall** and **LIBRARY – PET** using a visual basic (VB) code (described later). An overview of the sheet and its different sections are shown below.

Sections 1 and 2 represent the location that rainfall and potential evapotranspiration data are saved from the corresponding libraries. Section 3 populates the environmental context and determines if the selected year is a leap year using 'IsLeapYear()' function written in VB. Section 4 calculates the indoor water demand using a bottom-up water demand model developed by Makki et al. (2015). Section 5 summarises the input data including land covers, connection to the rainwater tank, and irrigation of certain zones. Section 6 is temporarily used for sorting rainfall and potential evapotranspiration data using the 'Calculation_Micro()' function written in VB. All cells in this section are cleared every time the function is activated.

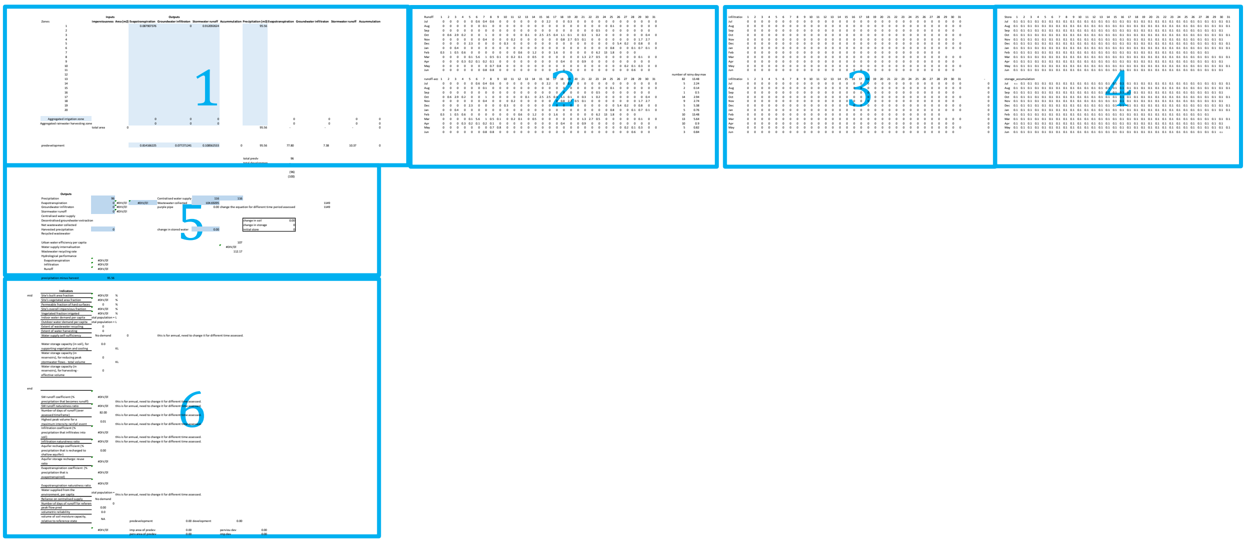


'MODEL – MUSIC – Site' calculates rainfall–runoff, rainwater harvesting, and irrigation. An overview of this sheet is shown below. The 'Calculation_Micro()' function copies key variables of each zone in section 1. For example, if the user defines six zones, the function runs six times. Key outputs of the zone are populated in section 2 (depending on timeframe assessed). Section 3 calculates rainfall–runoff for zones that are not linked to rainwater harvesting nor irrigated. The algorithm and equations used in this section can be found in Moravej et al. (in prep.) or in this link[2]. Sections 4 and 5 calculate the performance of rainwater harvesting systems and outdoor demand. Section 6 calculates natural flows for the pre-development case.



An overview of **'CALCULATION – Site'** is shown below. 'Calculation_Micro()' function copies the outputs calculated in the 'MODEL – MUSIC – Site' sheet to the 'CALCULATION – Site' sheet (section 1). Sections 2, 3, and 4 aggregate stormwater, infiltration, and storage respectively of all zones. Section 5 populates aggregated flows, which are used in section 6 to calculate the indicators. The function then copies the aggregated urban water flows and calculated indicators to the result sheet indicated by the user (result sheet 1 to 10) along with a summary of input data.

[2] https://wiki.ewater.org.au/display/MD6/Appendix+A%3A+Rainfall-Runoff+Modelling



Functions are written in VB codes and grouped in different modules, which you can access by clicking ‘Developer > Visual Basic’. The Developer tab is not displayed by default but users can add it to Excel by following this link[3]. Module 1 contains the ‘IsLeapYear()’ function. Module 2 writes the PET_micro and Rainfall_Micro functions, which are used to check missing data in the libraries and are activated when the user selects ‘Check rainfall data’ and ‘Check PET data’ buttons in the ‘INPUT – Site’ sheet. Module 6 writes the main function ‘Calculation_Micro()’. Module 5 contains functions for closing result sheets and moving back to the input sheet, opening the help sheet, and opening the user-defined input sheet.

[3] https://support.microsoft.com/en-us/office/show-the-developer-tab-e1192344-5e56-4d45-931b-e5fd9bea2d45

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