Operating Instructions for the online tool "rainwater harvesting and demand simulation" - a.k.a. http://GetTanked.org

Accessed from either instance http://rainwater.vpac.org or http://rainwater.vulabs.net

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These instructions are in support of the manuscript "*Transcontinental assessment of secure rainwater harvesting systems across Australia*",

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The author hereby documents recommended use of the online tool "rainwater harvesting and demand simulation" linked to from the website URL http://gettanked.org/, which serves only the Australian continent and Tasmania. This tool dynamically calculates the irrigation and evaporative cooling demands in addition to any particular per diem allocation of potable water. The analysis may be either from a finite storage tank of specified capacity, or drawn from water mains.

The nominal daily potable water demand of 144 litres per person per diem needs to be critically questioned by any user, and as a result of experience of the Millennium Drought it may be workable to reduce demand to 100 litres per person per diem, cover swimming pools, implement recycling of grey water to supplement irrigation, and to provide shade cloth cover over gardens during heat waves. In surviving drought it is reasonable to maintain the amenity of shade trees and a small garden as well as providing evaporative cooling indoors. If demand can be rationed and appropriately recycled, then secure rainwater harvesting system may be designed to serve in many parts of the Australian continent if sufficient catchment and capacity are provided, or if occasional tanker deliveries are readily available. Tables, sorted by climate classification are found in Appendices A through H of these instructions to tabulate demand restrictions that have been found to avoid running dry within the constraints of a nominal 10 m^3 capacity storage with 100 m^2 catchment– defining the sustainable load per diem (SLPD) during a "worst case" epoch – this is the break-point for absolute security as far as meteorological records can determine since European settlement.

SLPD varies from 86 to 124 L/d among most temperate maritime climate stations, and between 35 and 42 L/d at most desert climate stations. Appendix Tables A through H also summarize demand for evaporative cooling and irrigation together with the sustainable yield of a rainwater harvest system at 128 locations throughout Australia.

Indoor and potable water demand should be disaggregated from irrigation, pool evaporation, and evaporative cooling to make use of this tool.

Material and methods

FAO56 irrigation demand (Allen, et al. 1998), and pan evaporation reference the patched point dataset (PPD) data bank, commencing in 1890 for rainfall and 1957 for climate variables (Jeffery, et al. 2001). Daily minimum and maximum temperature and vapour pressure provided by the PPD, together with atmospheric pressure estimated from altitude are used to model the part-load performance of evaporative coolers if the full-load cooling demand is specified. Daily cooling load is scaled on basis of cooling degree days to the base 24°C as described by Peterson (2014) with design drybulb at the locality calculated for the specified epoch by the method of Peterson, et al. (2006). Backend computations and graphics are provided by GNU Octave following an M-file script that is customized in response to the details entered into data forms on the GetTanked website frontend. The website frontend is comprised of javascripts that were compiled with Google Web Toolkit.

In order to speed up simulations of multiple combinations of rainwater harvesting system parameters it was decided that the GetTanked tool must first-pass establish a “worst case” quadrennium (4 year epoch).at the case study of interest. The nomination of “worst case” is determined by searching for the two-consecutive years with respect to the difference between rainfall and Australian synthetic Class A pan evaporation. GetTanked includes the formative year as well as the succeeding year to nominate a moderated “worst case” epoch.

References

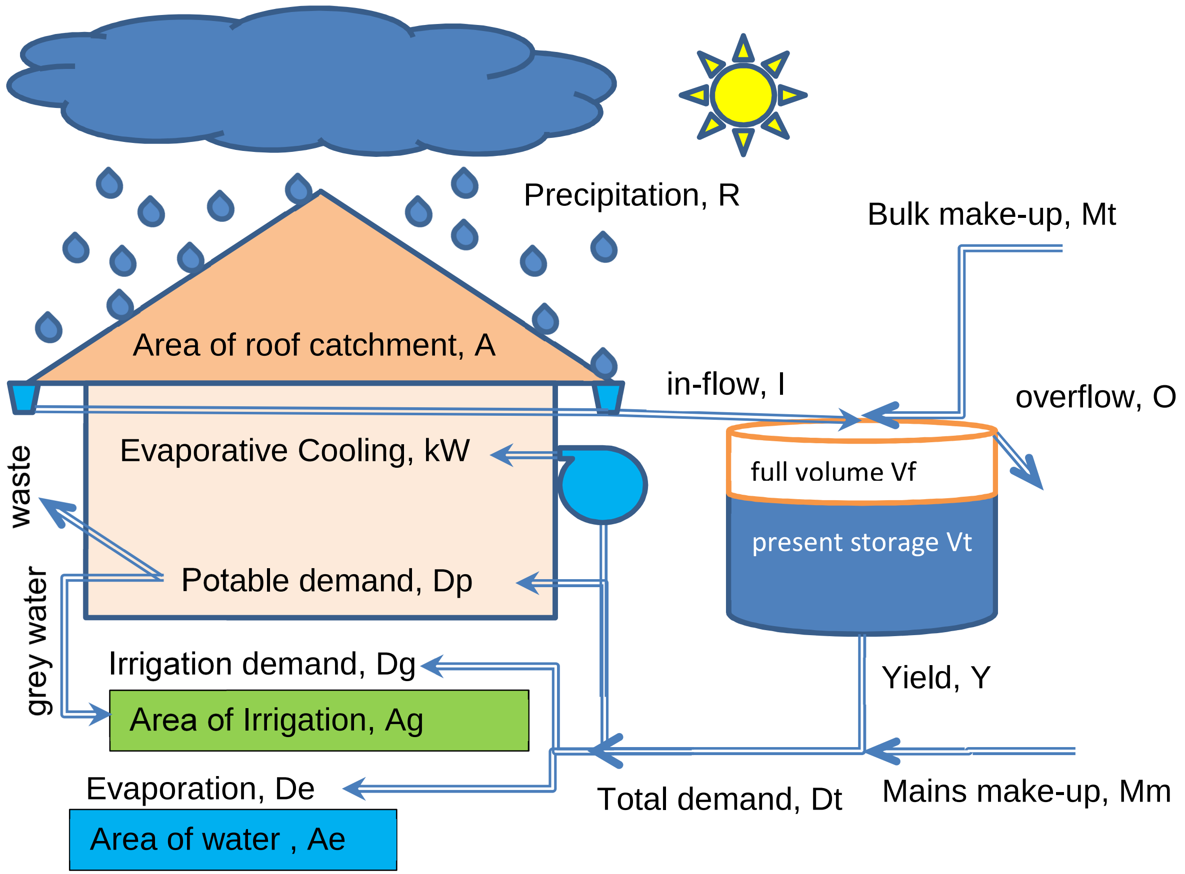
Allen RG, Pereira LS, Raes D, Smith M. 1998. Crop evapotranspiration—guidelines for computing crop water requirements: FAO irrigation and drainage paper 56. Rome: FAO–Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/X0490E/X0490E00.htm

Jeffrey, S. J., Carter, J. O., Moodie, K. B., & Beswick, A. R. (2001). Using spatial interpolation to construct a comprehensive archive of Australian climate data. Environmental Modelling & Software, 16(4), 309-330.

Peterson, E., Williams, N., Gilbert, D., & Bremhorst, K. (2006). New air conditioning design temperatures for Queensland, Australia. AIRAH Equilibrium February 2006. http://mail.airah.org.au/downloads/2006-02-01.pdf

Peterson, E (2014). Mitigation of the energy-water collision through integrated rooftop solar and water harvesting and use for cooling: A critical review. In: What conditions must models and methods fulfill on an urban scale to promote sustainability in buildings? Proceedings of the World Sustainable Building Conference 2014, Barcelona. ISBN 978-84-697-1815-5 http://uq.id.au/e.peterson/GetTanked/Peterson_ref110_Paper89.pdf

Graphical Abstract of Rain Water Harvesting and Demand Simulation (Peterson 2015)



Graphical Abstract: Rainwater harvesting and demand system (RWHS) modelled by the GetTanked tool from the paper "Transcontinental assessment of secure rainwater harvesting systems across Australia", Submitted to Resources, Conservation & Recycling 20th April 2015.

The parameters operating behind GetTanked are illustrated in the **Graphical Abstract** submitted to the journal Resources, Conservation & Recycling. Besides geographical location, adjustable variables include the potable water demand, $\mathbf{D_p}$, evaporative cooler capacity, **kW**, the area of garden irrigation demand, $\mathbf{A_g}$, the area of water feature evaporation, $\mathbf{A_e}$, utilized stormwater catchment area, **A** and the storage capacity of the tank, volume $\mathbf{V_f}$ when full, measured above the minimum allowed reserve. The geographical location determines the rainfall supply onto the roof catchment while solar radiation, temperature and humidity determine the FAO 65 evapotranspiration potential (irrigation demand), pan evaporation, and evaporative cooler water consumption. The level of water, $\mathbf{V_t}$, in the storage tank will generally vary at each timestep (daily) **t**.

As rainfall data is most generally available on a daily basis, GetTanked is designed to investigate the reliability of supply from rainwater with deficit periodically avoided by bulk delivery $\mathbf{M_t}$, or by continuous mains make-up $\mathbf{M_m}$. Simulations employ an algorithm where the present storage in the tank $\mathbf{V_t}$ is taken as the previous day's storage in the tank $\mathbf{V_{t-1}}$ minus the total daily demand, but not allowed to be negative, nor to exceed the maximum capacity of the tank. As yield is not explicitly calculated to determine occasional tank overflows, this model uses yields-before-spill (YBS). GetTanked operates with an in-built assumption of 10 litres first flush diversion each day that rainwater harvesting occurs. The behaviour of supplemental water imports depends if there is a continuous connection to mains for makeup on demand $\mathbf{M_m}$, or if bulk shipments are hauled in to fill the tank whenever it runs dry.

GetTanked users can toggle the "water consumption" data entry form to evaluate the continuous-mains make-up, or estimate tanker-trucking orders for premises that are off-grid. Bulk tanker deliveries are the method of makeup employed example output Figures 1 – 5, but mains connected refilling without storage capacity or catchment informs the seasonal demand profiles of irrigation and evaporative cooling. Bulk tanker make-up is normal practice in situations of rural and peri-urban development, where home owners need to ensure that they hold water reserves for fire fighting. There is very little spillage before use as such tanker deliveries tend to be conducted during periods of drought, and so the YBS model is a reasonable method for the purposes of the present study. In either case, yield from the RWHS ($\mathbf{Y_t}$) can be calculated as the minimum of total daily demand ($\mathbf{D_t}$); or the sum of daily in-flow (**I**) and the previous day's storage ($\mathbf{V_{t-1}}$).

GetTanked utilizes Google Maps interface for users to specify location and the trace the catchment areas **A** that contribute to the RWHS. The nominated storage tank capacity $\mathbf{V_f}$ should be considered by the user by reference to manufacturer's specification to neglect sludge collection at the bottom and freeboard in the headspace. For example, a 2.2 m internal diameter tank would need to exceed 2.63 m height to achieve 10 kL capacity $\mathbf{V_f}$, and higher to ensure this represents the active-capacity above any required low-level reserve.

The GetTanked Google Maps interface also allows users to trace the area of evapotranspiration $\mathbf{A_g}$ and evaporation demand $\mathbf{A_e}$, or explicitly specify these areas. GetTanked users may vary the portion of the rooftop rainfall (**R** × **A**) entering the inflow of the tank by adjusting the impermeability of the catchment (nominally 0.95). Similarly the user may vary the FAO56 irrigation demand (**FAO56** – **R)** × $\mathbf{A_g}$ by specifying a screening factor (nominally 0.0). Finally the user may vary water feature (i.e. swimming pool or open-air reservoir) evaporation by specifying a cover factor (nominally 0.0).

Rainwater harvesting and demand simulation data forms

The rainwater harvesting and demand simulation tool URL http://GetTanked.org has been forwarding to a server at premises of the Victorian Partnership for Advanced Computing (VPAC), 110 Victoria Street, Melbourne, Australia, but may be redirected elsewhere. In any instance the website, “Rain Water Harvesting and Demand Simulation”, presents a series of data forms for users to specify rainwater catchment, water usage and tank storage capacity to simulate the reliability of supply from rainwater, and to identify supplements that may be required.

GetTanked estimates the 'failure rate', being the percentage of imports either made-up from water mains or by tanker truck deliveries. The left hand pane of GetTanked has a green arrow that notes the user’s progress working through seven data-entry forms between ***Welcome*** and ***Submit***, with “< Prev” and “Next >” to forward and back as much as desired until selecting ‘Submit’ on the last form, with a wait of up to two minutes for results. Users can revise successive simulations with the “< Prev” and “Next >” toggles, and then submit again before copying resulting graphics (Figures 1 through 5) for pasting into a report.

1. ***Location*** is the first data entry form (after the *Welcome* notice). Select location by either typing in an address or clicking in the Google Maps window. This is the only input for which there is no default, and so we illustrate VPAC’s street address “110 Victoria Street, Melbourne” or geographical coordinates “-37.8066 , 144.9635”. Beware GetTanked runs for any point on earth, using the nearest Australian dataset.

2. ***Analysis Period*** is the second data entry form. “Worst Case” or “Manual” specification will be confirmed in Figure 1 in red against the background 121 years of PPD. In the current study the default “Worst Case” option is always accepted, simply advancing “Next >”.

3. ***Water consumption*** specifies either “Total Consumption” or “Consumption based on household population”. The latter is the default, with 2 persons dwelling in the home, with 155 L “Daily water consumption per person”. This default is equivalent to entering 310 L/day “Total daily consumption” under the alternative tab. Enter 0 if rainwater harvesting system does NOT serve POTABLE needs, and advance to further data forms to detail modelling of demand for irrigation, evaporative-cooling, and evaporation from swimming pools and water features. Accept default of 155 L per capita per diem, advancing “Next >”.

4. ***Rain water collection and storage*** is the fourth data entry form. Users may specify if mains water is available, but the default setting (“No”) assumes that a water tanker is despatched to fill the tank if it runs dry. Demand without reference to supply will be profiled if mains water is declared to be available while also zeroing both tank size and roof size. This form allows adjustment of nominal default 10,000 L *capacity*, nominal 100 m^2 *catchment* and the rather optimistic suggestion of 95% *run-off coefficient (1-permeability*$_{catchment}$*)*. Note that “capacity” is intended to represent only the active-capacity of a covered storage reservoir, excluding any required reserve. Google imagery is provided to measure catchment area by tracing polygons over any number of discernible impervious surfaces judged to be useful.

5. **Outdoor water use** is covered by two data- entry forms, each provided with a Google imagery view of the locality of interest so that the user can trace polygons over the areas of garden irrigation and water body evaporation that demand water from the rainwater harvesting

tank. Manual data entry of the square meters of irrigated garden and pool area are also provided, with default at zero. If an area is entered and traced then the default portion covered is zero, which can be adjusted as high as 1 to indicate the area could somehow be absolutely protected from evaporation or evapotranspiration. Zero cover is assumed throughout the present example. In the present discussion accept all defaults, with zero area of both garden irrigation and pool evaporation, and also without evaporative cooling. Thereby only a constant demand for potable water is simulated. Evaporative cooling has been included on the “outdoor water use” form because the process depends on forced convection of outdoor air through the building to displace heat with air approaching the wetbulb temperature of the outdoor air conditions. The evaporative cooling model integrated into GetTanked was described by Peterson (2014), and depends on the user declaring the total cooling capacity of installed evaporative coolers. Direct evaporative cooling does not work when wetbulb temperatures are above the desired indoor temperature of 24°C, and therefor at such times vapour-compression air-conditioning systems could be desired. GetTanked models the consumption of water effectively evaporated, and so splits the demand peaks of spring and autumn – indicating evaporative cooling is often ineffective during summer in such locations.

6. **Outdoor water use continued** The second outdoor water use form is concerned with evaporation from uncovered water features such as swimming pools or any storage reservoir exposed to pan-like evaporation losses. For the initial illustration of methodology without non-potable demands accept all defaults on both “Outdoor Water Use” forms, simply stepping forwards “Next >” and then “Next >”

7. **User contact details** Ambit users may directly click the final “Next >” to skip past the 7th form unless willing to collaborate with the author in a case study or to offer critique. Use of this form is necessary if the user wishes to request a copy of the M-file script that runs on the server, but it is also best to email the author as a prompt because the user register is rarely used and so routine monitoring has not been justified.

The forgoing data-forms are analysed by selecting the ”Submit” button to pass parameters to a computer server with results to be displayed once the simulation has completed. It usually takes just one minute for a four-year analysis (default) if no other users happen to submit a job at the same moment. Analysis with evaporative cooling may take two minutes. Figures 1, 2, 3, 4, 5, and “*Summary*” appear on completion. Select the desired figure tab and then click within the figure to maximize the display and then click again to review other figures or to review data entry forms from “< Prev”. Users may copy figures using right mouse-key “Save picture as”, or “copy” and then paste into a document together with *Summary* text.

Repeatedly skipping through all forms (“Next>”) without amending anything other than the address ignores the buildings that may be discerned in Google imagery. The default 10,000 L active-volume of the tank is fed by 100 m^2 catchment with 95% runoff coefficient (5% permeability) supplying a fixed 310 L daily demand during the particular location’s “worst case” quadrennium (4 years period covering an El Niño event).

Scripting GetTanked Rain Water Harvesting and Demand Simulation

While all of the results presented in these operating instructions were obtained via the GetTanked website interface, interested researchers and professionals could run simulations offline if they install MatLAB or Octave and obtain PPD data from Queensland Science Delivery Division of the Department of Science, Information Technology, Innovation and the Arts (DSITIA) https://www.longpaddock.qld.gov.au/silo/ppd/format.php specified to be in the "Standard including FAO56 Reference Evapotranspiration (ETo)" format and copy into a data folder with the station identification number appended by ".txt" suffix.

Each run of the on-line GetTanked tool is custom written in the GNU Octave M-file script that can be obtained by completing the user contact details before submitting a simulation to the GetTanked server http://rainwater.vpac.org. It is then recommended to email the author because user comments are rarely completed, and so the feedback register is seldom monitored. The author can reply with the user's simulation script, but it must be renamed something short ending with the M-file suffix ".m" and amended wherein the UNIXpath2SILO and/or DOSpath2SILO variables match the local users' "data" repository of PPD files and an ASCII file named "station_ID_altitude.csv" containing four columns of comma separated station identifier (sorted by ascending BoM number), latitude (°), longitude (°), elevation (m) for each station of the "data" subfolder:

$station_1$, $latitude_1$, $longitude_1$, $elevation_1$
$station_2$, $latitude_2$, $longitude_2$, $elevation_2$
…
$station_n$, $latitude_n$, $longitude_n$, $elevation_n$

In the example simulation at the premises of VPAC the station_ID_altitude.csv should contain at least one line "86071,-37.8075,144.97,31.2" while the folder "data" must contain a PPD file named "86071.txt" if not all of the 4759 stations that can be subscribed to.

Furthermore the header of PPD files are six lines longer than those that were integrated into the on-line GetTanked tool and so the M-file script must be amended such that lines defining "unix_command1" and "dos_command1" should be replaced as follows:

```
unix_command1=['sed "1,54d" ',filename,' > ',filelessheader];
dos_command1=['more +54 ',filename,' > ',filelessheader];
```

Default output for example address in Melbourne: 110 Victoria Street, Melbourne, Australia

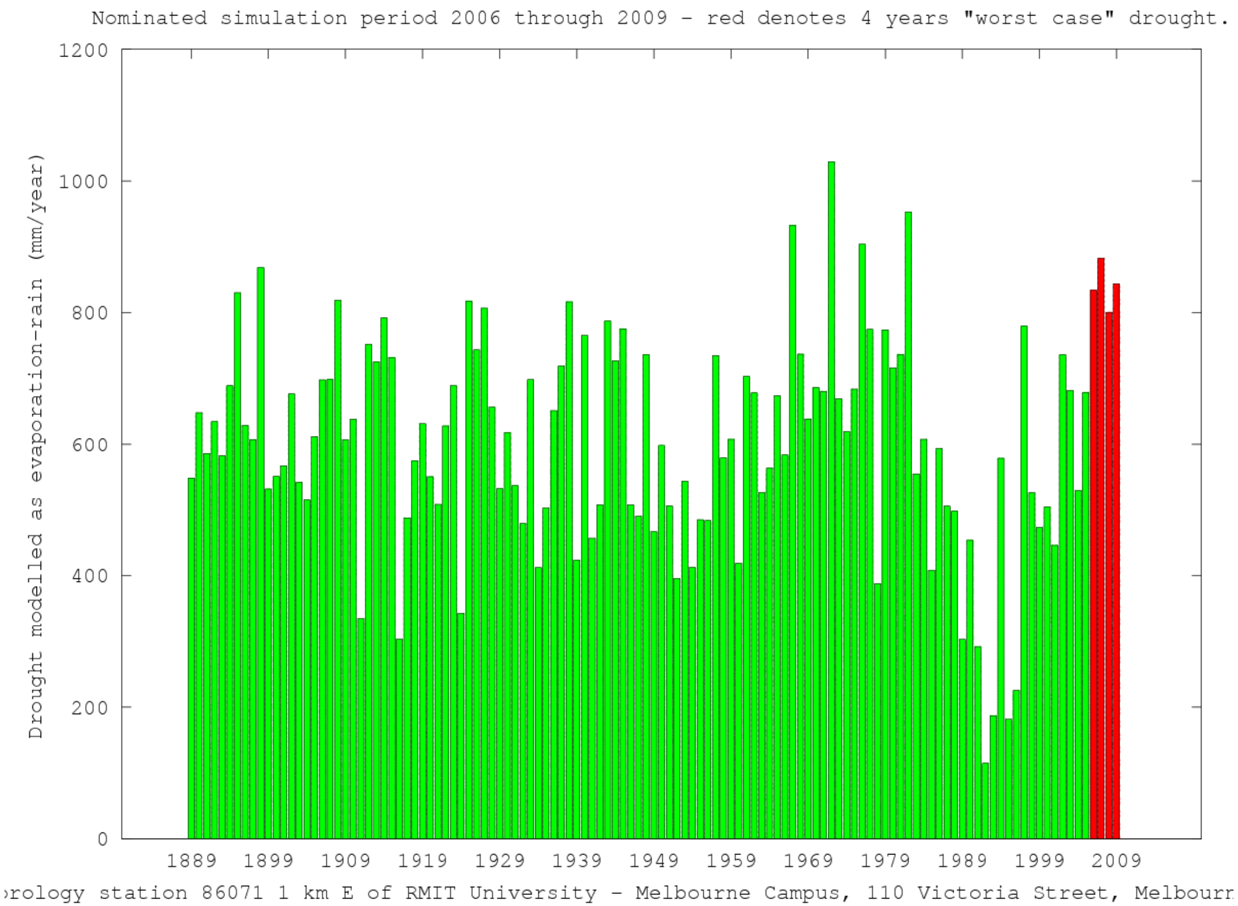


Figure 1: Default output from website GetTanked.org "Figure 1" for Melbourne. The difference between evaporation and rainfall over 121 years.

Default output for the example address "110 Victoria Street, Melbourne", Figure 1, illustrates that the "worst case" quadrennium was taken at the end of the available time series, immediately before the return of La Niña wet seasons 2010 and 2011. The vertical axis is the difference between Australian synthetic Class A pan evaporation and rainfall.

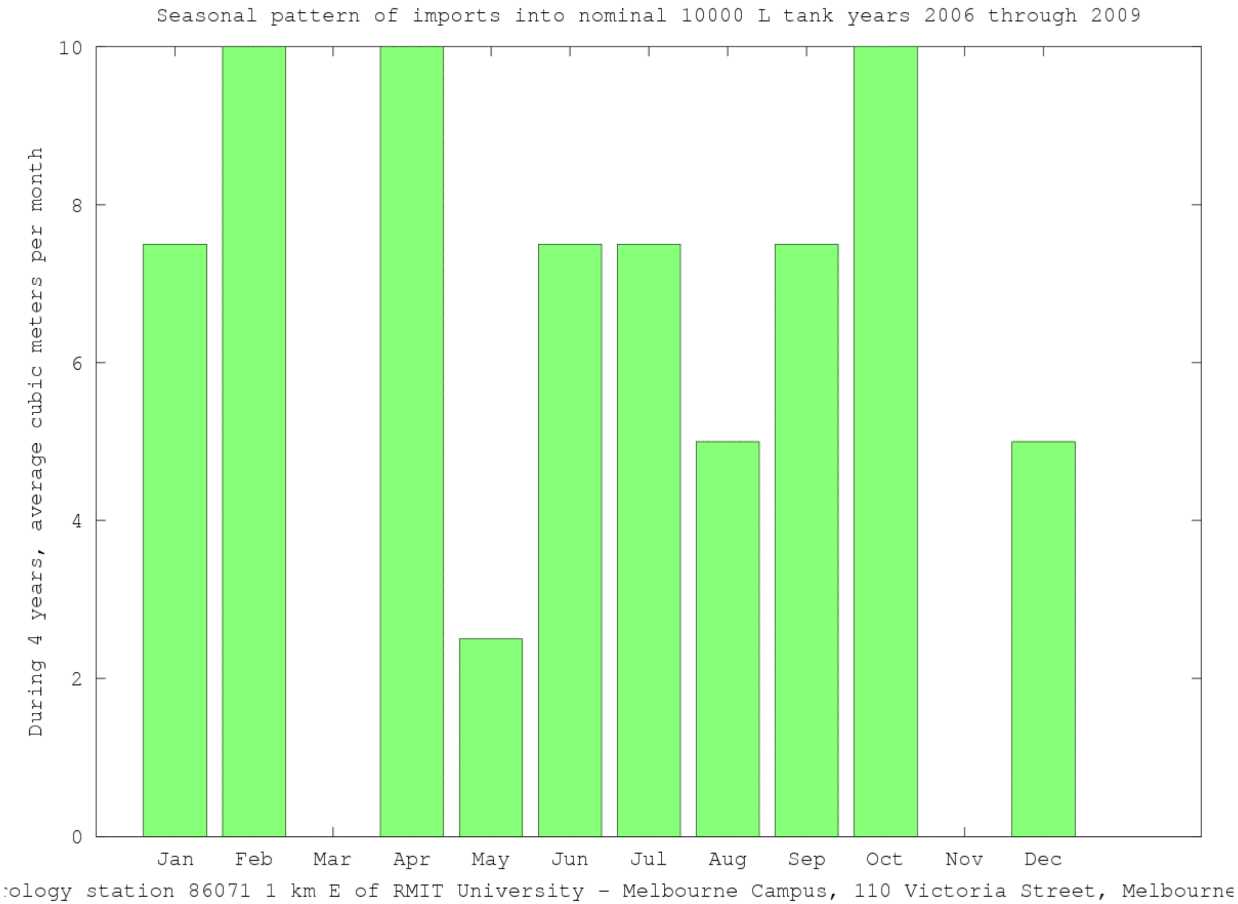


Figure 2: Default output from website GetTanked.org "Figure 2" for Melbourne. Average monthly water make-up requirement during simulation epoch.

Default output Figure 2 presents the seasonal pattern of imports into a 10,000 L tank over the epoch 2006 through 2009, and confirms that simulations are based on Bureau of Meteorology station 86071, lying about one km east of the location of interest. During the 4 years of simulation the average monthly demand for trucking imports is presented. Note that the months of February, April, and October averaged a delivery of one 10 kL shipment of water. It appears that no shipments were required in March or April of the epoch, and that deliveries were not required all of four instances of the other months during the epoch. Beware this plot averaged monthly demand over the four year epoch.

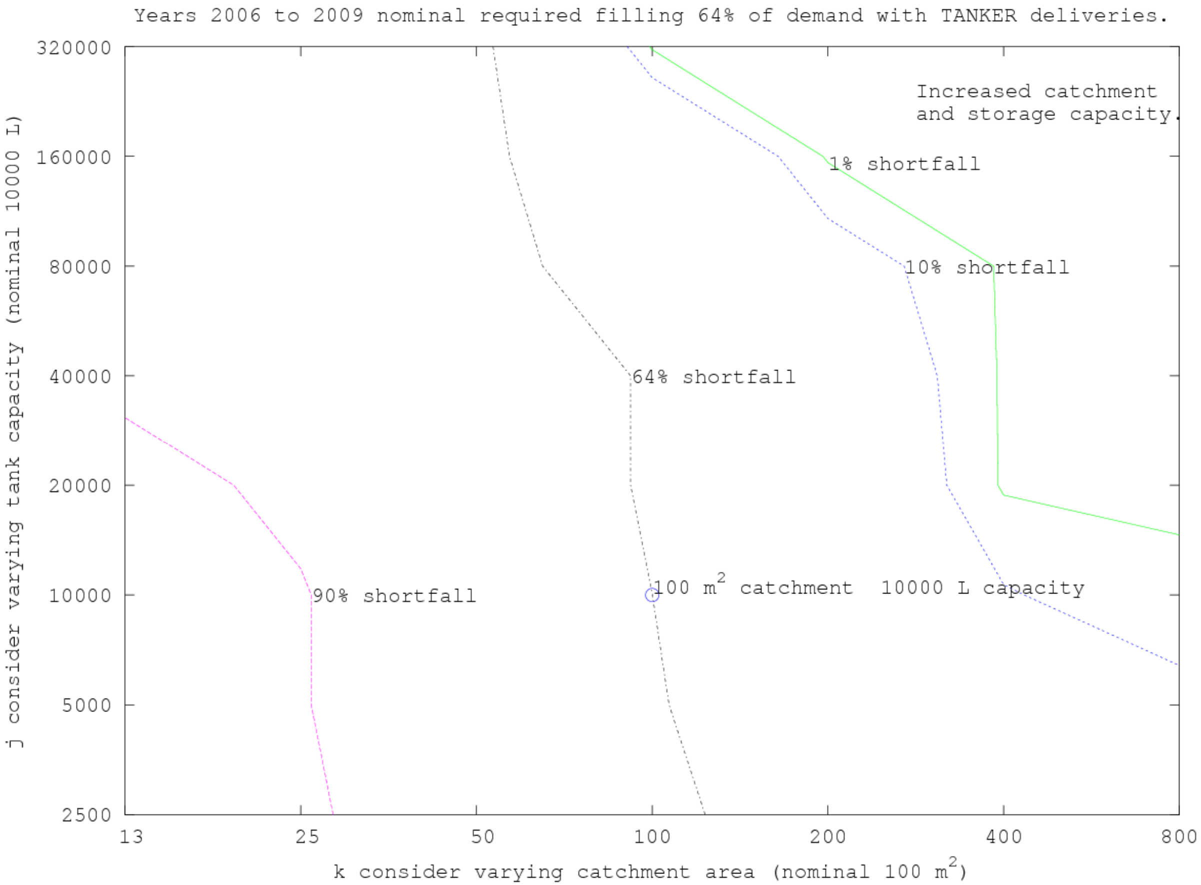


Figure 3: Default output from website GetTanked.org "Figure 3" for Melbourne. Import requirement varies with tank capacity and catchment area.

Default output Figure 3 presents 56 (8 × 7) variations of tank capacity and catchment area surrounding the nominal 10,000 L tank and 100 m² roof catchment, with the statement that 64% of demand during the epoch (2006-2009) would have required tanker deliveries. The contour of 1% shortfall makes it clear that a quadrupling of both tank capacity and roof catchment would reduce demand for imports near zero. Due to the logarithmic character of this graphic, there is no point in combinations of capacity and catchment far beyond the contour of 1% shortfall. The contour of 10% shortfall suggests possibly economic solutions if occasional refilling by tanker trucking is feasible.

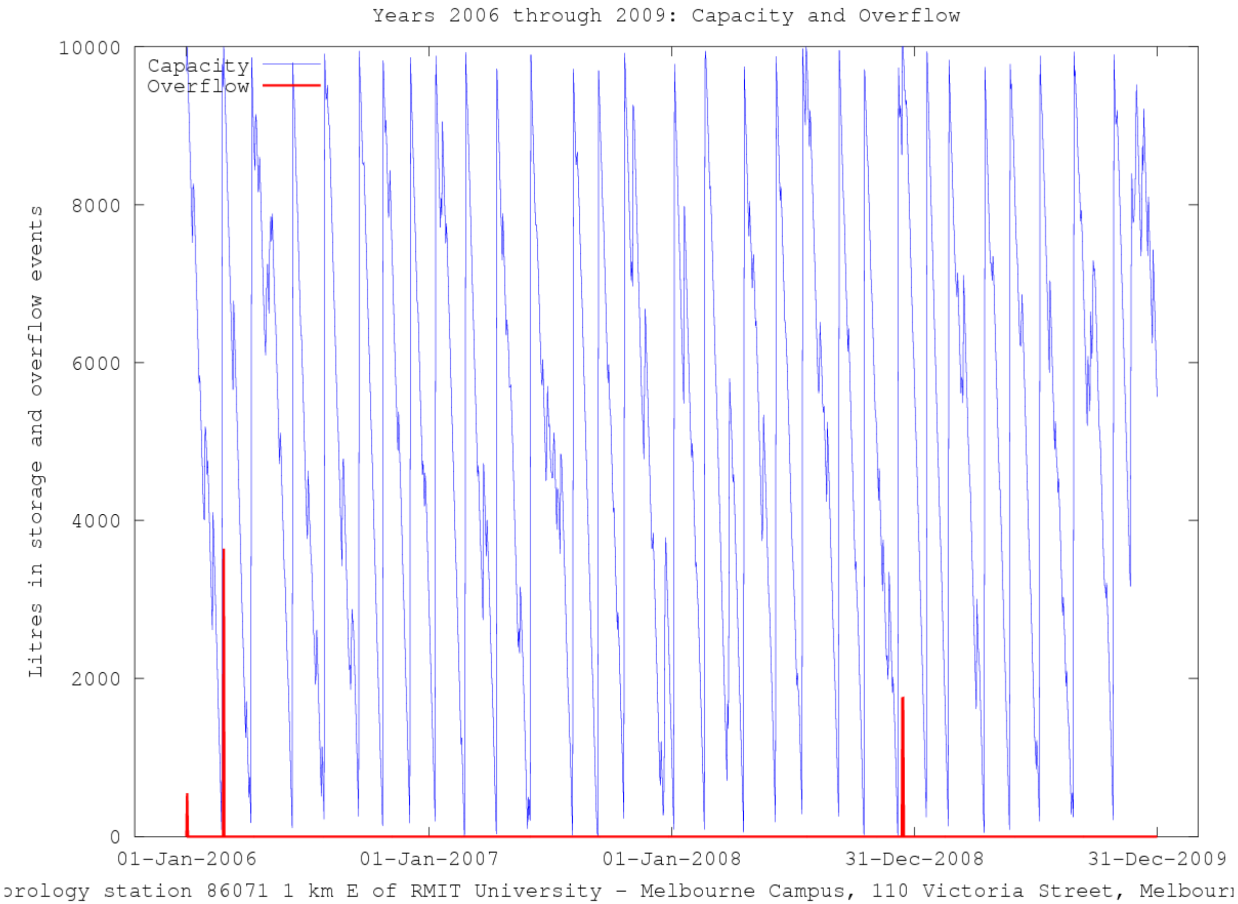


Figure 4: Default output from GetTanked.org "Figure 4" for Melbourne. Timeline of tank capacity and overflows for nominal capacity and catchment area

Default output Figure 4 provides a daily time-series of the tank capacity and overflow events during the epoch (2006-2009). Rainwater overflow events indicate that more tank capacity would be useful to avoid later demand for refilling. Tanker truck deliveries are implied when the capacity curve runs vertically from near zero, up to near the nominated capacity level (10,000 L) without the coincidence of overflow. There are 29 tanker filling events observed on this plot that can be confirmed by reference to the average monthly demand for imports presented in Figure 2.

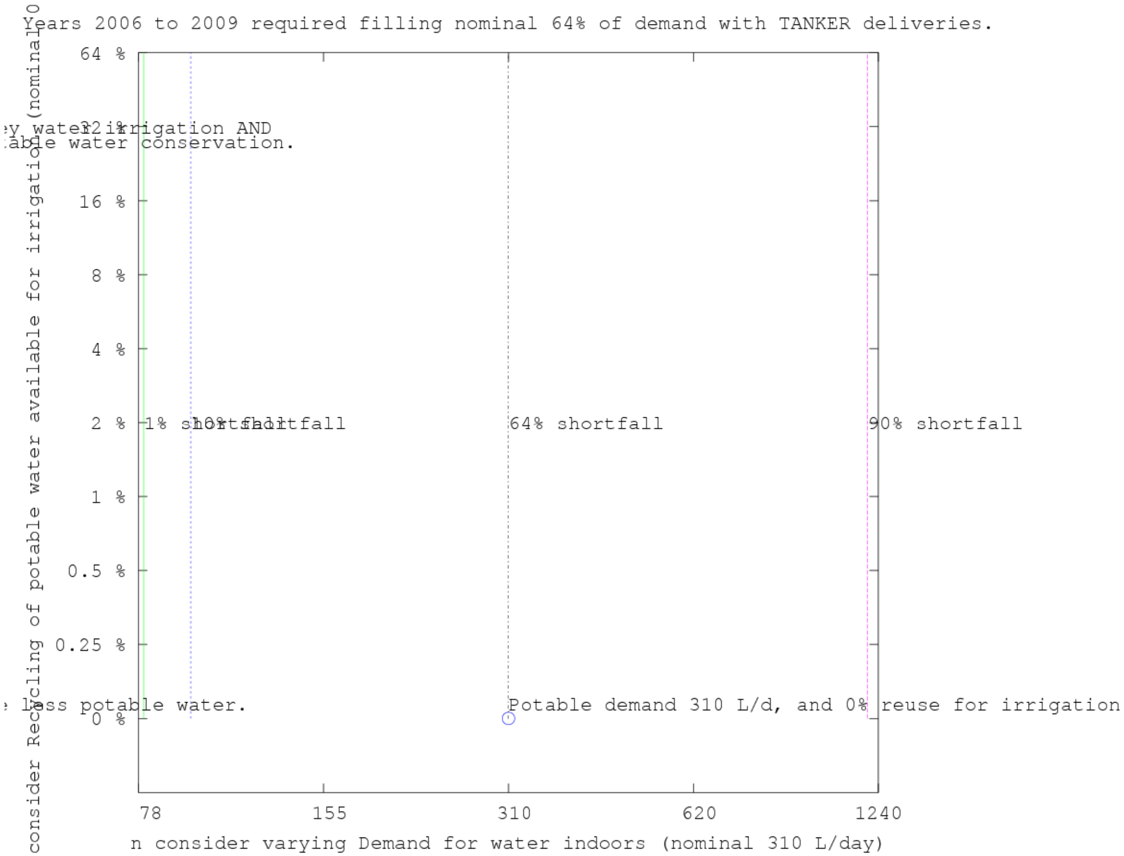


Figure 5: Default output from website GetTanked.org "Figure 5" for Melbourne. Import requirement varies with recycling of grey water to supplement outdoor irrigation. Without specification of irrigated area the only advice of this figure is to manage the daily demand for potable water indoors.

Default output Figure 5 is similar to Figure 3 by stating the nominal RWHS would have required tanker truck deliveries to make-up 64% of demand, but in the case of Figure 5 the nominal among 60 combination (10 × 6) variations of demand and increasing rates of recycling grey-water after use as indoor potable water to meet irrigation needs outdoors, and by varying the demand for indoor potable water. Truncated text in the upper left corner is intended to label "Grey water irrigation AND potable water conservation" Truncated text in the lower left corner is intended to label "Use less potable water". Unfortunately the contour labels of 1% shortfall and 10% shortfall are overwritten.

Workflow recommendations

A number of useful outputs require comparative re-simulation as they are not available first-pass through the rain water harvesting and demand simulation tool that is found from the link at URL GetTanked.org

For example Sustainable Litres Per Diem **(SLPD*)** in the example of default output for Melbourne, Figure 5 resolves that the demand should be managed somewhere above 78 and below 155 litres per day during the “worst case” drought epoch. The particular breakpoint was later found to be 104 L/d at the example address. The breakpoint is here-to-for referred to as *SLPD** where the asterisk denotes that 10,000 L storage and 100 m^2 catchment defaults apply. The Appendix tables present the SLPD* found at 128 locations around Australia, but at any other location the user is offered the following workflows to determine their locally relevant values of key indicators of RWHS performance.

a. Sustainable Load Per Diem

The sustainable demand per diem was determined by repeatedly stepping back and forth between the water consumption and submit forms, with a delay of one minute per iteration. Each time inspect Figure 5 and note percentage filling required as well as the demand level closest to the curve of 1% shortfall. Iteration steps are manually continued until they confine the breakpoint of absolute reliability, between two steps separated by one litre per diem. The result is the sustainable load per diem (*SLPD**) at the location of interest, where the asterisk indicates the default storage capacity of 10,000 litres and catchment area of 100 m^2. For example *SLPD** is found to be 104 L/d at the example address of 110 Victoria Street, Melbourne. In many locations SLPD* is less than 100 L/d, in which case the percentage shortage over the drought epoch (***short***) is tabulated in Appendices A-H so that tanker supplements can be arranged if demand remains at constant level of 100 L/d.

b. Irrigation (Irrig †)

Irrigation demand of any particular situation is obtained by stepping back (“<Prev”) three data entry forms to specify irrigated garden area, then back (“<Prev”) another data entry form to toggle ***YES*** with regard to mains water supply and to ***zero*** both tank size and roof size, and then back (“<Prev”) one more data entry form to ***zero*** potable consumption. Finally forwarding (“Next>”) five data entry forms and reactivating the “Submit” button produces a revised set of Figures 1 through 5. Specifying 10 m^2 irrigation in the otherwise default output for 110 Victoria Street, Melbourne yield revised *Summary Results text*: “Assuming an irrigated garden and/or lawn area of 10 square meters.” and “Lawn and garden demand was 100%. The total average demand was 29 L/d, with maximum 92 L/d.”

Summary Results text also includes the average and maximum daily demand that would be met with a limitless water mains service – without the nominal rainwater harvesting system. Divide irrigation demand by the irrigated area and report as **Irrig** †, 2.9:9.2 L/d/m^2 (av:max).

c. Greywater irrigation (recycling indoor potable water after first use)

It is reasoned that a per diem ration of 100 litres of potable water may be manageable while non potable demands are also supplied as needed. This suggests two persons dwelling under 100 m^2 adapting lifestyle to severe drought restrictions, or one person living more lavishly therein. Having completed irrigation-only demand results, step back (“<Prev”) five forms to toggle “Total Consumption” and specify the total daily consumption at 100 litres per day (per diem). Then step forward (“Next>”) one form to toggle “No” mains connection and restore the nominal RWHS (roof size 100 m^2 feeding 10,000 L tank size). Finally step forward to reactivate the “Submit” button and wait a minute. In the case of Melbourne the nominal RWHS serving 10 m^2 of garden, then reliability is ensured if 64% of potable demand is recycled for irrigation – otherwise tanker deliveries are required to make-up 21% of demand during the “worst case” epoch, denoted in the revised output “Figure 5”.

d. Evaporative cooling demand per diem per kW capacity (ECDkW)

Back step and zero all dataforms, except to specify the house equipped with an evaporative cooler having a nominal capacity of 3.5 kW (1 ton of avoided air-conditioning), and step forward to reactivate the “Submit” button and wait two minutes. In this example GetTanked has simulated a 1 ton (3.5 kW) evaporative cooling system’s performance in Melbourne, where Summary Results report an average 18 L./d demand with peak 166 L/d. Revised “Figure 2” shows the peak occurs in March and a secondary peak in January. In the case of Melbourne the result range 5 to 47 L/d/kW and are listed in the results of this study as the evaporative cooling demand per kW capacity, 5:47 **ECDkW** L/d/kW (av:max).

e. Total demand for potable water, irrigation, and evaporative cooling (TPIE ‡)

Total demand including 100 L/d potable as well as irrigating 10 m^2 and 1 ton evaporative cooling is found to average 147 L/d with a peak of 309 L/d in January. Coincidentally, the peak is near Melbourne Water’s drought management “Target 155” for two persons. In the example of Melbourne, one reliable solution to the problem of ensuring 100 L/d potable supply plus irrigation of 10 m^2 garden and 1 ton (3.5 kW) evaporative cooling is to increase storage to 14,000 litres and catchment to 141 m^2, while providing grey water recycling or provide imports as illustrated in revised output “Figure 5”.

Acknowledgements

GetTanked was made possible by Victoria University of Technology, which joined the Victorian Partnership for Advanced Computing (VPAC), to provide logistical support to develop innovative interactive tools. VPAC provided the GetTanked website to read my program script with open source Octave. Lachlan Hurst developed the Google Maps mashup “front end” alpha version, with final version of the website developed by Daniel Micevski. Resources, Conservation & Recycling peer-reviewers suggested these operating instructions be freely posted on-line.

Appendix A: Tropical group, Am and Aw monsoon and savanna climates, typified by Cairns and Bowen

placename	dry epoch		climate	100m^2 10kL 100L/d short	**SLPD*** (L/d)	**Irrig †** (L/d/m^2)		pk. mo.	Cooling Design db/wb		**ECDkW** L/d/kW av:max		pk. mo.	**TPIE ‡** total Pot. +Irrig +Evap (L/d)	
COOKTOWN QLD	2002	2005	Aw	14%	87	3.6	:8	10	35.5	/26.6	8	:49	8	163	:309
CAIRNS QLD	**2002**	**2005**	**Am**	**14%**	**71**	**3.5**	**:8**	**10**	**34.0**	**/24.9**	**9**	**:55**	**8**	**168**	**:329**
DARWIN NT	1978	1981	Aw	27%	63	3.8	:7	9	35.4	/25.8	4	:25	7	153	:248
BOWEN QLD	**2001**	**2004**	**Aw**	**41%**	**51**	**4.0**	**:7**	**11**	**33.8**	**/26.7**	**13**	**:67**	**8**	**187**	**:372**
GOVE NT	1951	1954	Aw	44%	51	3.6	:6	10	33.5	/26.1	5	:23	8	151	:233
PORT KEATS NT	1991	1994	Aw	41%	47	4.2	:8	10	38.1	/27.4	6	:36	7	163	:273
NORMANTON QLD	1970*	1973*	Aw	41%	46	5.0	:9	10	39.1	/23.9	8	:38	7,11	176	:278
GEORGETOWN QL	1969	1972	Aw	41%	46	5.0	:9	10	39.9	/23.5	10	:47	7	185	:309
TOWNSVILLE QLD	1993	1996	Aw	34%	44	4.1	:9	1,10	35.0	/24.0	12	:66	7	184	:369
TINDAL NT	1961	1964	Aw	34%	43	4.7	:8	10	40.1	/26.3	9	:43	6,10	179	:295

* Normanton's epoch 1970-'73 caused a failure of evaporative cooling calculations, so years 2006-2009 used for ECDkW and TPIE results.

Appendix B: BSk cold semi-arid (steppe) climate, typified by Mildura

placename	dry epoch		climate	100m² 10kL 100L/d short	**SLPD*** (L/d)	**Irrig †** (L/d/m²)		pk. mo.	Cooling Design db/wb		**ECDkW** L/d/kW av:max		pk. mo.	**TPIE ‡** total Pot. +Irrig +Evap (L/d)	
KYANCUTTA SA	2006	2009	BSk	34%	65	3.7	:10	1	43.6	/22.4	9	:45	10,12	170	:293
NORSEMAN WA	1971*	1974*	BSk	34%	62	3.7	:9	12	40.7	/22.7	9	:53	12,3	169	:318
LAKE GRACE WA	1972	1975	BSk	27%	62	3.4	:9	12	39.3	/21.1	8	:51	3,12	163	:323
SOUTHERN CROSS	1976	1979	BSk	41%	59	4.0	:9	1	40.8	/20.1	8	:50	11,4	168	:310
WAILLTON VIC	1981	1984	BSk	21%	56	2.9	:9	12	40.5	/21.6	7	:52	12,2	155	:327
MILDURA VIC	**2006**	**2009**	**BSk**	**55%**	**51**	**3.9**	**:9**	**1**	**41.9**	**/21.3**	**8**	**:43**	**12**	**166**	**:293**
SWAN HILL VIC	1981	1984	BSk	27%	49	3.5	:9	1	41.3	/21.6	8	:40	12,3	162	:290
RENMARK WA	2002	2005	BSk	48%	45	3.8	:10	1	41.1	/20.7	10	:51	3,12	172	:306

* Norseman's dry epoch 1971-1974 caused a failure of evaporative cooling calculations, so year 2006-2009 used for ECDkW and TPIE results.

Appendix C: BSh hot semi-arid climate, typified by Charleville

placename	dry epoch		climate	100m² 10kL 100L/d short	**SLPD*** (L/d)	**Irrig †** (L/d/m²)		pk. mo.	Cooling Design db/wb		**ECDkW** L/d/kW av:max		pk. mo.	**TPIE ‡** total Pot. +Irrig +Evap (L/d)	
TENNANT CREEK N	1985	1988	BSh	48%	76	5.6	:9	11	41.5	/21.4	10	:33	1	193	:287
CUNNAMULLA QLD	2005	2008	BSh	34%	66	4.8	:9	1,10	43.1	/22.2	8	:40	9,4	127	:233
DALWALLINU WA	1976	1979	BSh	27%	63	4.1	:10	1	41.7	/21.3	8	:39	11,4	168	:288
QUILPIE QLD	2005	2008	BSh	34%	60	5.1	:9	1,10	43.2	/25.2	9	:41	5,9,1	183	:286
COBAR NSW	2005	2008	BSh	41%	57	4.4	:9	1	41.9	/20.5	7	:38	10,4	168	:304
EMERALD QLD	2002	2005	BSh	27%	52	4.6	:9	11	40.1	/24.7	10	:50	8,5	182	:313
KUNUNURRA WA	1985	1988	BSh	41%	51	5.4	:9	10	42.5	/27.6	7	:25	7,10	179	:269
WYNDHAM WA	1989*	1992*	BSh	34%	51	5.6	:9	10	42.1	/27.4	6	:29	7,10	173	:280
CHARLEVILLE QLD	**1991**	**1994**	**BSh**	**41%**	**50**	**4.7**	**:9**	**1**	**39.8**	**/21.4**	**11**	**:55**	**9,5**	**186**	**:341**
KALGOORLIE WA	1976	1979	BSh	55%	45	4.2	:9	1	41.0	/20.4	8	:45	10,4	169	:295
WINTON QLD	1982	1985	BSh	55%	45	5.3	:9	12	42.6	/23.1	10	:49	8,5,1	189	:311
MOUNT ISA QLD	1985	1988	BSh	48%	44	5.5	:9	1,10	41.2	/22.5	11	:50	8,1	193	:315
BROOME WA	1992	1995	BSh	51%	38	5.1	:9	11,3	38.6	/22.9	9	:43	7	182	:295
CURTIN WA	1971	1974	BSh	41%	37	5.2	:9	10	41.0	/24.2	8	:37	7,11	179	:272
RICHMOND QLD	2002	2005	BSh	48%	36	5.5	:9	10,3	41.7	/23.4	11	:45	7	195	:299
LONGREACH QLD	2002	2005	BSh	55%	32	5.5	:9	12	42.5	/21.9	11	:48	8,5	195	:310

* Wyndham's epoch 1989-1992 caused a failure of evaporative cooling calculations, so years 2006-2009 used for ECDkW and TPIE results.

Appendix D: Desert group, BWh and BWk hot outback and cold nullarbor climates, typified by Woomera and Broken Hill

placename	dry epoch		climate	100m² 10kL 100L/d short	**SLPD*** (L/d)	**Irrig †** (L/d/m²)		pk. mo.	Cooling Design db/wb		**ECDkW** L/d/kW av:max		pk. mo.	**TPIE ‡** total Pot. +Irrig +Evap (L/d)	
LEARMOUTH WA	1978	1981	BWh	55%	47	5.3	:10	12	42.1	/23.6	9	:38	9,5,2	185	:288
URANDANGI QLD	1989	1992	BWh	48%	44	5.6	:9	12	43.7	/23.9	10	:44	8,1	191	:295
CARNARVON WA	1988	1991	BWh	62%	42	4.6	:9	12	40.9	/20.5	7	:41	5,10	171	:284
FORREST WA	1977	1980	BWh	62%	42	4.1	:10	1	41.8	/19.5	10	:46	10,3	176	:303
MEEKATHARRA W	1969	1972	BWh	55%	41	5.1	:9	12	41.7	/20.1	8	:36	1,9,4	179	:285
WINDORAH QLD	1969	1972	BWh	55%	38	5.3	:10	1	43.0	/22.1	10	:41	5,9,1	188	:298
LEONORA WA	1976	1979	BWh	55%	37	4.8	:9	1	43.2	/20.1	7	:39	4,10	174	:284
WOOMERA SA	**2006**	**2009**	**BWh**	**62%**	**36**	**4.6**	**:10**	**1**	**42.7**	**/20.3**	**7**	**:37**	**10,4**	**170**	**:299**
BOULIA QLD	2006	2009	BWh	62%	35	5.6	:10	10,3	43.7	/24.4	10	:36	8,5,1	190	:299
BROKEN HILL NSW	**1981**	**1984**	**BWk**	**55%**	**35**	**4.1**	**:9**	**1**	**42.0**	**/22.2**	**8**	**:42**	**3,10**	**167**	**:286**
BIRDSVILLE QLD	1971	1974	BWh	55%	30	5.1	:10	12	44.7	/22.7	8	:34	9,1,5	179	:297
PORT HEDLAND W	1971	1974	BWh	62%	27	5.5	:10	11	43.1	/22.4	9	:33	7	186	:294
ROEBOURNE WA	1982	1985	BWh	62%	26	5.9	:10	12	43.9	/23.1	9	:29	8,1	190	:291

Appendix E: Csa west coast mediterranean climate, typified by Geraldton

placename	dry epoch		climate	100m² 10kL 100L/d short	**SLPD*** (L/d)	**Irrig †** (L/d/m²)		pk. mo.	Cooling Design db/wb		**ECDkW** L/d/kW av:max		pk. mo.	**TPIE ‡** total Pot. +Irrig +Evap (L/d)	
MANDURA WA	1977	1980	Csa	21%	76	3.3	:9	1	37.0	/21.8	7	:43	4,12	157	:296
PERTH ARPT WA	1994	1997	Csa	27%	69	3.6	:9	1	39.7	/21.3	7	:42	11,3	162	:295
LANCELIN WA	1994	1997	Csa	27%	63	3.4	:9	1	38.0	/20.1	7	:43	3,1	158	:305
GERALDTON WA	**1976**	**1979**	**Csa**	**27%**	**60**	**4.0**	**:9**	**12**	**41.4**	**/20.9**	**8**	**:39**	**11,4**	**167**	**:280**
PERTH CITY WA	1993	1996	Csa	21%	59	3.4	:9	1	38.1	/20.8	7	:42	12	158	:293

Appendix F: Csb oceanic mediterranean climate, typified by Adelaide City

placename	dry epoch		climate	100m² 10kL 100L/d short	**SLPD*** (L/d)	**Irrig †** (L/d/m²)		pk. mo.	Cooling Design db/wb		ECDkW L/d/kW av:max		pk. mo.	**TPIE ‡** total Pot. +Irrig +Evap (L/d)	
CURRIE TAS	1981	1984	Csb	0%	120	1.6	:7	1	27.7	/20.0	3	:99	2	125	:483
MT GAMBIER SA	1981	1984	Csb	0%	114	2.1	:9	1	37.8	/18.4	5	:55	1	138	:343
ALBANY WA	1994	1997	Csb	0%	110	2.3	:9	1	33.4	/20.3	7	:77	1,4	146	:427
MT. LOFTY SA	2006	2009	Csb	0%	100	2.9	:9	1	38.1	/19.9	6	:48	1	150	:322
LAVERTON VIC	1981	1984	Csb	7%	99	2.5	:9	1	38.1	/20.7	5	:60	11,2	143	:348
ADELAIDE CITY SA	**1976**	**1979**	**Csb**	**7%**	**95**	**3.1**	**:9**	**1**	**37.1**	**/20.0**	**5**	**:48**	**1**	**150**	**:317**
CAPE LEEUWIN WA	2001	2004	Csb	21%	94	2.6	:8	12	27.4	/17.4	3	:71	2,4	135	:395
MORUYA HDS NSW	1979	1982	Csb	7%	88	2.5	:8	12	32.1	/20.6	5	:89	2,9	142	:450
ESPERANCE WA	1972	1975	Csb	7%	87	2.9	:9	12	38.1	/21.4	8	:53	12	157	:327
KATANNING WA	1977	1980	Csb	21%	81	3.0	:9	1	37.7	/22.0	9	:55	12	161	:341
ADELAIDE ARPT SA	2006	2009	Csb	27%	73	3.3	:9	1	39.4	/20.8	6	:44	1	153	:304
NEPTUNE ISL SA	2006	2009	Csb	21%	63	2.6	:7	1	28.7	/19.2	3	:84	1	136	:444

Appendix G: Cfa humid sub-tropical climate, Typified by Brisbane

placename	dry epoch		climate	100m² 10kL 100L/d short	**SLPD*** (L/d)	**Irrig †** (L/d/m²)		pk. mo.	Cooling Design db/wb		**ECDkW** L/d/kW		pk. mo.	**TPIE ‡** total Pot. +Irrig +Evap (L/d)	
CAPE MORETON QLD	2000	2003	Cfa	0%	159	3.0	:8	1	30.2	/23.8	7	:63	11,4	153	:335
SYDNEY CITY NSW	1979	1982	Cfa	0%	132	2.9	:8	12	33.9	/21.8	6	:53	3,9	150	:328
WILLIAMTOWN NSW	1979	1982	Cfa	0%	129	2.9	:9	12	37.8	/24.0	8	:56	4,12	156	:334
NEWCASTLE NSW	1979	1982	Cfa	0%	125	2.7	:8	12	34.0	/22.2	5	:67	9,3	143	:362
SYDNEY ARPT NSW	1979	1982	Cfa	0%	125	2.9	:9	12	35.6	/23.2	6	:53	3,9	151	:326
COFFS HARBOUR NSW	1979	1982	Cfa	0%	117	2.7	:8	12	32.8	/22.9	9	:75	4,12	159	:409
MARYBOROUGH QLD	1979	1982	Cfa	0%	111	3.2	:8	11	34.3	/25.3	16	:89	9,5	189	:440
BANKSTOWN NSW	1979	1982	Cfa	0%	100	3.0	:9	12	37.7	/23.0	8	:56	4,10	158	:336
BURRINJUCK NSW	2006	2009	Cfa	0%	100	3.2	:9	1	39.1	/23.3	7	:52	10,12,3	158	:323
ARCHERFIELD QLD	1993	1996	Cfa	7%	98	3.3	:9	12	35.4	/22.9	13	:69	9,4	178	:378
GOLD COAST QLD	1996	1999	Cfa	7%	98	2.8	:7	12	31.7	/23.8	10	:85	4,11	163	:445
COONABARABRAN NS	2002	2005	Cfa	7%	96	3.3	:8	1	38.0	/21.8	13	:68	3,11	180	:386
BRISBANE QLD	**1993**	**1996**	**Cfa**	**7%**	**96**	**3.1**	**:8**	**12**	**33.7**	**/22.5**	**13**	**:77**	**4,9**	**175**	**:418**
COOLANGATTA QLD	2001	2004	Cfa	7%	89	2.9	:8	1	32.2	/23.7	12	:90	11,4	170	:445
YOUNG NSW	2006	2009	Cfa	14%	86	3.1	:9	1	38.1	/21.4	9	:67	12,3	164	:371
WAGGA WAGGA NSW	2006	2009	Cfa	14%	79	3.6	:9	1	40.8	/20.3	8	:54	10,3	164	:335
SCONE NSW	1979	1982	Cfa	7%	78	3.4	:9	12	39.4	/23.3	10	:60	4,10	170	:339
MOREE NSW	2002	2005	Cfa	7%	78	4.1	:9	1	39.6	/23.1	10	:55	10,4	177	:323
ROMA QLD	2001	2004	Cfa	21%	76	4.3	:9	1	39.6	/22.7	11	:57	9,4	182	:343
GAYNDAH QLD	2005	2008	Cfa	7%	76	3.8	:8	12	37.7	/25.6	14	:63	5,9	188	:358
MUDGEE NSW	1979	1982	Cfa	7%	69	3.3	:9	12	37.4	/22.5	10	:70	3,10	169	:389
NULLO MTNS NSW	1979	1982	Cfa	14%	68	3.1	:8	12	36.4	/21.1	10	:66	3,12	167	:381
ST LAWRENCE QLD	2001	2004	Cfa	27%	65	4.1	:8	11	35.7	/25.3	14	:59	8,5	190	:341
GLADSTONE QLD	2001	2004	Cfa	21%	64	4.1	:8	11	35.2	/24.7	11	:48	8,5	178	:306
ROCKHAMPTON QLD	2001	2004	Cfa	27%	64	4.2	:9	12	38.2	/25.7	12	:51	8	183	:325

Appendix H: Cfb maritime climate, typified by Melbourne

(First of two pages)

placename	dry epoch		climate	100m² 10kL 100L/d short	**SLPD*** (L/d)	**Irrig †** (L/d/m²)		pk. mo.	Cooling Design db/wb		**ECDkW** L/d/kW av:max		pk. mo.	**TPIE ‡** total Pot. +Irrig +Evap (L/d)	
PALMERS LOOKOUT T	2006	2009	Cfb	0%	172	1.7	:7	1	26.4	/17.9	2	:82	1	124	:436
CAPE BRUNY TAS	1988	1991	Cfb	0%	161	1.5	:7	1	26.4	/16.4	2	:71	1	120	:397
WONTHAGGI VIC	1971	1974	Cfb	0%	157	1.9	:8	1	32.5	/21.7	7	:87	3	143	:436
GELLIBRAND VIC	2005	2008	Cfb	0%	153	2.0	:8	1	33.6	/18.9	4	:67	3,12	134	:380
WILSONS PROM VIC	2006	2009	Cfb	0%	146	2.0	:8	1	30.9	/20.3	3	:77	12,3	131	:407
LATROBE VALLEY VIC	1971	1974	Cfb	0%	142	2.1	:8	12	33.6	/21.4	7	:68	3,12	145	:388
CAPE OTWAY VIC	2006	2009	Cfb	0%	138	2.0	:8	1	31.4	/18.8	3	:90	10,3,1	131	:459
MAATSUYKER ISL TAS	2006	2009	Cfb	0%	138	1.5	:7	2	26.0	/14.9			NaN	120	:401
GABO ISLAND VIC	1979	1982	Cfb	0%	137	2.0	:6	1	25.7	/20.1	2	:101	1	128	:494
CAPE GRIM TAS	2003	2006	Cfb	0%	125	1.6	:6	1	23.0	/17.6	1	:67	2	111	:153
WYNYARD TAS	2006	2009	Cfb	0%	123	1.8	:7	1	26.4	/17.5	3	:90	1,11	129	:479
KATOOMBA NSW	1979	1982	Cfb	0%	121	2.3	:8	12	32.2	/18.8	7	:81	12	146	:441
LAUNCESTON TAS	1982	1985	Cfb	0%	117	2.0	:7	1	29.8	/18.7	8	:115	2	148	:555
WARRNAMBOOL VIC	1981	1984	Cfb	0%	117	2.0	:8	1	36.5	/21.1	4	:65	2,11	133	:374
CERBERUS VIC	2006	2009	Cfb	0%	113	2.2	:9	1	35.8	/21.3	5	:63	3	138	:364
SHEOAKS VIC	2006	2009	Cfb	0%	109	3.3	:9	12	35.8	/20.2	7	:63	1,3	148	:368
MORTLAKE VIC	1981	1984	Cfb	0%	109	2.2	:9	2	36.0	/20.9	5	:61	2	140	:365
HOBART CITY TAS	2006	2009	Cfb	0%	108	2.2	:8	1	30.5	/17.9	5	:97	1	141	:490
RHYLL VIC	2006	2009	Cfb	0%	108	2.2	:9	1	34.5	/21.4	5	:59	3	138	:347
MOUNT BOYCE NSW	1979	1982	Cfb	0%	106	2.4	:8	12	32.0	/18.8	7	:85	12	149	:443

Appendix H continued: Page two of two maritime climate

placename	dry epoch		climate	100m² 10kL 100L/d short	**SLPD*** (L/d)	**Irrig †** (L/d/m²)		pk. mo.	Cooling Design db/wb		**ECDkW** L/d/kW av:max		pk. mo.	**TPIE ‡** total Pot. +Irrig +Evap (L/d)	
NOWRA NSW	1979	1982	Cfb	0%	104	2.8	:8	12	35.1	/21.9	7	:55	12,3	153	:335
ULLADULLA NSW	1979	1982	Cfb	0%	104	2.5	:8	12	33.0	/21.4	7	:75	12,3	150	:403
MOORABBIN VIC	2006	2009	Cfb	0%	104	2.5	:9	1	37.3	/21.4	6	:57	1,3	146	:344
EDDYSTONE PT TAS	1997	2000	Cfb	0%	104	2.1	:7	12	25.3	/18.6	2	:80	2,12	126	:422
MELBOURNE VIC	**2006**	**2009**	**Cfb**	**0%**	**104**	**2.9**	**:9**	**1**	**37.5**	**/20.9**	**5**	**:47**	**3,1**	**147**	**:309**
HAMILTON VIC	1981	1984	Cfb	0%	104	2.2	:8	1	37.1	/19.5	6	:57	2,12	145	:336
MT. WELLINGTON Ts	1967	1970	Cfb	0%	100	2.1	:8	1	30.9	/18.6	6	:109	1	142	:534
DEVONPORT TAS	2006	2009	Cfb	7%	96	2.0	:6	1	25.4	/18.0	2	:89	2	127	:469
EAST SALE VIC	2005	2008	Cfb	7%	90	2.4	:8	1	34.6	/21.5	9	:83	1	154	:428
BOMBALA NSW	1903	1906	Cfb	7%	87	2.2	:6	1	30.1	/20.0	13	:113	1	168	:531
MANGALORE VIC	2006	2009	Cfb	14%	84	3.1	:9	1	39.6	/22.0	8	:59	12,3	159	:349
GEELONG VIC	2006	2009	Cfb	14%	84	2.4	:9	1	37.1	/20.6	5	:62	3,11	142	:358
ARARAT VIC	1981	1984	Cfb	7%	83	2.5	:9	1	37.0	/20.3	7	:67	12,2	149	:376
BRAIDWOOD NSW	1979	1982	Cfb	14%	83	2.5	:8	12	33.4	/19.7	9	:86	12,2	158	:456
BEGA NSW	1979	1982	Cfb	14%	82	2.7	:9	1	36.6	/22.4	12	:78	3,12	170	:411
GOULBURN VIC	1979	1982	Cfb	7%	82	2.7	:8	12	35.4	/21.1	9	:73	12	159	:396
BATHURST NSW	1981	1984	Cfb	7%	77	2.7	:8	1	36.0	/21.7	9	:71	12	160	:397
CANBERRA ACT	1979	1982	Cfb	7%	73	2.9	:8	1	36.1	/20.9	10	:72	12	164	:390
HOBART ARPT TAS	2006	2009	Cfb	14%	73	2.3	:8	1	30.7	/18.5	5	:110	12,3	142	:535