water by design
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WaterWise
Street Trees

Calculating the optimal catchment size for street tree vitality

Published 20.07.18

Photo: Celeste Morgan E2Designlab

passive irrigation:

Get the water to where it's needed and let nature do the rest

Modelling Passively Watered Street Trees and Wicking Beds for the GBR and SEQ

Introduction

Stormwater, when viewed as a locally available low-cost water source, can open up many opportunities for creating cooler, healthier and more liveable communities, as well as improving the quality and reducing the volume of stormwater flowing to receiving environments.

This project, a joint initiative between State Government (DES), Healthy Land and Water and **Townsville, Cairns, Rockhampton, Mackay, Sunshine Coast** and **Ipswich City** Councils, has undertaken soil moisture and water quality modelling to inform the design of street trees and wicking beds in the different rainfall regions of Queensland. This provides more options for ensuring water quality objectives can be met, while also helping to ensure the viability of street trees and other public open space all with using less potable water. The outcomes of this modelling provides confidence to decision makers, designers and implementers that these solutions are viable in each of the rainfall regions.

This investigation has enabled appropriate design parameters to be defined to assist in the broader implementation of these technologies for water quality, landscape and microclimate benefits. The intent of this fact sheet is to provide general information and guidance to inform higher level planning (i.e. allocating space during master planning by applying the catchment area ratios). This fact sheet is not intended for concept or functional/detailed design. Further work is required to prepare a design guidline for passively watered street trees and wicking beds. Please contact Healthy Land and Water or E2Designlab for further design guidance in the interim.

E2DESIGNLAB

water by design an initiative of Healthy land & water

Key Terms

Passive Watering – irrigation of landscapes without the use of energy (e.g. no pumps). This typically involves using gravity to direct rainfall runoff from adjacent surfaces onto vegetation

Saturated Hydraulic Conductivity – ease with which pores of a saturated soil permit water movement

Stormwater – rainwater that runs off surfaces such as roofs and roads

Treatment Area to Catchment Area Ratio (TCAR) – the area of catchment from which runoff is generated compared to the surface area of the tree pit or wicking system

Tree Pit - the hole in the ground in which a tree is planted and backfilled with topsoil. In the urban context the pit may represent the whole of the space available for root growth

Wicking Bed - a landscape area (turf open space or vegetated garden bed) that has a reservoir of water below the topsoil layer from which water is draw upwards like a wick to the soil layer above

Benefits of Passive Watering

The drivers and objectives for passively watered solutions include:

- Provide a **healthy** growing environment for the targeted species, be that street trees or turf, this includes adequate soil volume and soil moisture (being not too wet or too dry)
- Support landscapes with **alternative water** sources to increase landscape health, resilience and amenity
- Achieve local **microclimate** cooling benefits
- **Reduce reliance** on potable water supplies
- **Protect receiving environments** (i.e. waterways, estuaries, oceans) by providing at-source detention, treatment and reuse of stormwater
- **Reduce demands** on existing stormwater networks and delay future augmentation
- **Reduce** need for active irrigation and associated **costs** (i.e. pipes, pumps, sprinklers, energy, maintenance)
- Provide an alternative stormwater **treatment solution** to bioretention basins, constructed wetlands and proprietary filters

Passively Watered Street Trees

In the urban context, where surrounding soils are often compacted and/or other infrastructure and footings are present, the tree pit may represent the total space available for root growth (Figure 1). Sizing the tree pit to support a tree to reach its full growth potential becomes critically important. Similarly, in urban environments where there are surrounding impervious surfaces such as roads and pavement, there is limited opportunity for rainfall to penetrate soils and replenish soil moisture. Passively watered tree pits overcome these challenges by directing runoff, via surface grading (gravity) to the tree pit (Figure 2). This method of irrigation does not require the use of energy (e.g. no irrigation pumps) and minimises the consumption of potable water.

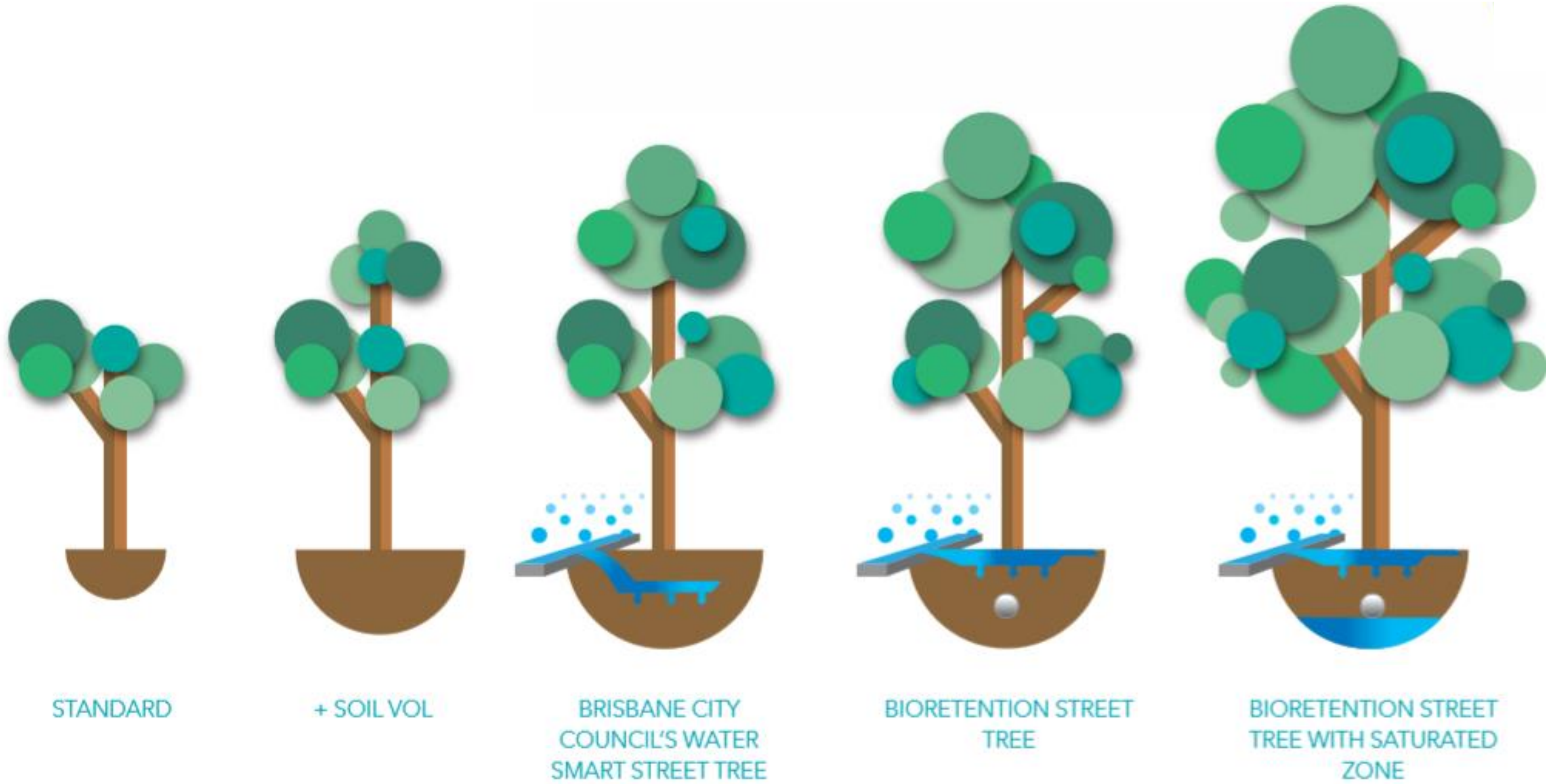


FIGURE 1. STANDARD TREE PITS IN URBAN ENVIRONMENTS WITH LIMITED ACCESS TO WATER + EXAMPLES OF PASSIVELY WATERED TREE PITS, WITH INCREMENTALLY IMPROVED SOIL MOISTURE LEVELS, TO SUPPORT TREE HEALTH AND INCREASED CANOPY COVER

Passively watered tree pits will typically incorporate an inlet (e.g. kerb cut-out); a soil in which the tree roots grow and allow water to infiltrate; and a drainage layer to enable excess water to discharge from the base. Tree pits may also incorporate an 'optional' saturated wicking zone which holds water in the base to provide soil moisture during dry periods. The soil surface of the tree pit is set down below the pavement and road level, typically by 100mm, to enable water to be captured (extended detention) and spread over the tree pit surface. Once the tree pit fills and backwaters onto the road, flows will continue down the kerb and gutter to a stormwater side entry pit. It is the access to regular small inflows that provide watering and soil moisture that benefit the tree.

By sizing the tree pit to match the growing requirements of the tree species and directing the right amount of water to the tree, optimal growing conditions are created, and stormwater is utilised as a resource. This overcomes the challenges of poor quality compacted soils and low soil moisture levels which is common in urban areas with impervious surfaces.

The other important feature of passively watered street trees, optimised for both soil moisture and stormwater treatment, is the soil selection. The soil must both support tree growth and support pollutant removal. Sandy loam and loamy sand topsoils generally fall within this category provided they aren't too high in nutrients or organic matter, as this may result in nutrient leaching, or too high in fines (clay and silt). The Water by Design Bioretention Technical Design Guidelines (2014) filter media specification can be referred to as a general guide, noting that more freely draining soils are used in bioretention systems. In tree pits a saturated hydraulic conductivity in the range of 50mm/hr to 100mm/hr is preferable. Figure 3 provides a typical cross section through a passively watered street tree including the 'optional' saturated zone.

Modelling Passively Watered Street Trees

Method -– how do we know what design configurations will work in each climatic zone?

Detailed modelling was undertaken to inform the design of passively watered street trees, this included:

- Rainfall Analysis - to confirm the most appropriate rainfall data set for each climatic region (Figure 4)
- Soil Moisture Modelling - evapotranspiration modelling and soil moisture data analysis to determine to occurrence of overly saturated conditions (too wet) and identification of dry spells below wilting point (too dry)
- MUSIC Modelling - water quality modelling to demonstrate stormwater pollutant removal performance

For each climatic zone, the following scenarios were modelled:

- 2 x water use levels - low-medium water use trees and high water use trees
- 2 x soil types - sandy loam 50mm/hr and loamy sand 100mm/hr
- 2 x design configurations - tree pits with and without a saturated wicking zone
- Treatment area to catchment area ratios - of 1% to 10%

Tree pits can be represented in MUSIC using an adapted bioretention node. Design and modelling parameters are provided at the back of this fact sheet. This is provided as a general guide only and is not intended to inform detailed concept or functional design. A design guideline for passively watered trees is proposed as a piece of future work.

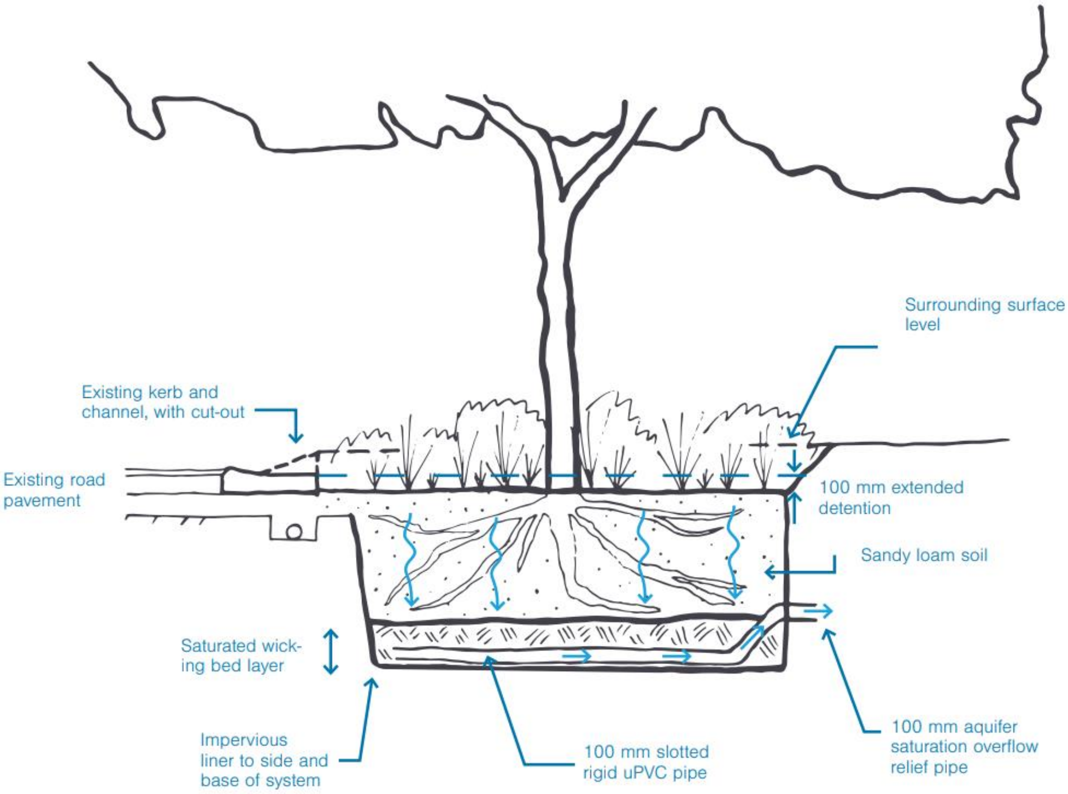


FIGURE 3. TYPICAL CROSS SECTION THROUGH A PASSIVELY WATERED STREET TREE WITH SATURATED WICKING ZONE

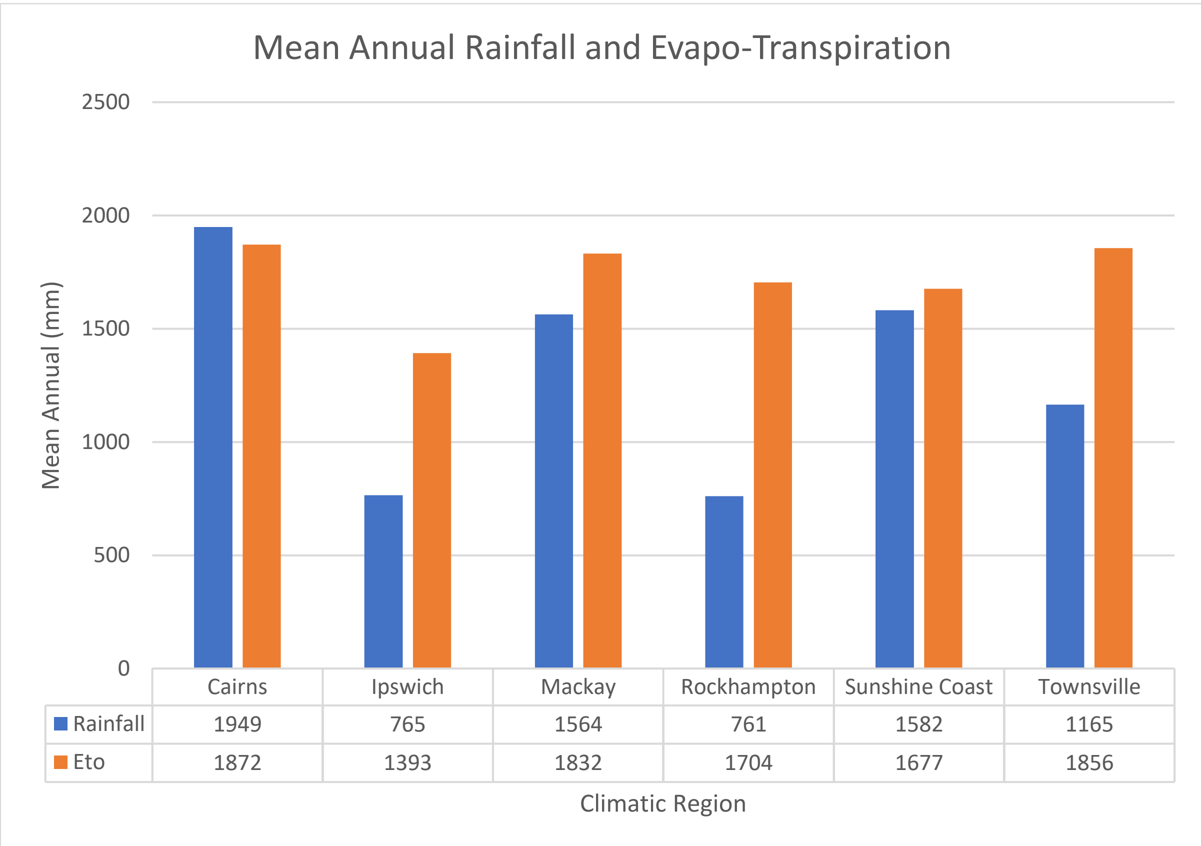


FIGURE 4. COMPARISON OF MEN ANNUAL RAINFALL AND EVAPOTRANSPIRATION FOR THE CLIMATIC REGIONS MODELLED

Applying the outcomes to design

The results of the modelling summarised in this fact sheet can be used in several ways to inform the design process of passively irrigated systems. The design process involves close collaboration between landscape architects, water sensitive designers and civil engineers, to realise the multiple benefits they can deliver. An example of a process in which these modelling results, presented as treatment area to catchment area ratios (TCAR), may be used to inform the design of street tree pits is outlined below:

1. Landscape architects should provide early advice to define a street tree planting layout and species schedule which is appropriate to the local climatic conditions and character of the area.
2. Adequate soil volumes are defined for the chosen tree species.
3. Treatment area (i.e. tree pit surface area) to catchment areas ratios (TCAR) are utilised to determine the maximum and minimum catchment areas which can be directed to each tree pit to ensure optimum soil moisture is available. Catchment areas to a tree pit can be optimised by altering the spacing of inflows, location of tree pits, road gradings, or in the case of inadequate stormwater inflows, additional sources such as roofs or air-conditioning condensate could be utilised.
4. In dry climatic regions, or for systems with undersized catchments, a saturated water storage zone (wicking layer) at the base of the tree pit may be included to increase a systems resilience to dry spells.
5. Finally, the system can be modelled to determine the stormwater quality treatment performance and quantify its benefit towards protecting and enhancing the environmental values and water quality of Queensland waters (SPP 2017).

The design process should be iterative, to achieve the objectives of the project. For example, if the objective is to meet the full stormwater management objectives within the streetscape (i.e. at-source rather than end of line stormwater treatment), additional street trees or larger tree pits may be an option.

Greenfield development or urban renewal projects typically offer the greatest opportunity to incorporate passively irrigated tree pit systems to achieve optimal outcomes. That is, tree pits with target soil volumes; catchment areas within the optimal range for soil moisture; and underdrainage (where a stormwater connection is feasible).

In retrofit situations site constraints such as underground services may limit the tree pit size available and the area of contributing catchment. It may also be more difficult and costly to incorporate underdrainage. The modelling undertaken allows the design team to make informed decisions with regards to retrofitting in street tree pits in constrained sites. If the tree pit design falls within the "too dry" category, more drought tolerant tree species can be selected, and/or supplementary irrigation provided. Where the tree pit falls within the "too wet" category and/or underdrainage cannot be provided, trees adapted to tolerating 'wet feet' could be selected, and/or the extended detention depth reduced (to reduce the volume of inflows), noting that this will reduce the stormwater treatment performance.

The value of this modelling work is in understanding the likely soil conditions within passively irrigated systems to be able to make informed design choices.

Is it a low or high water use tree?

All trees will increase their transpiration in hot urban environments when there is a good supply of soil moisture. The typical tree characteristics below can be used as a guide to determine the water use of a selected tree species and the most appropriate reference data to use in Table 1.

Characteristics of low water use trees:

- Leaves with thick and/or waxy cuticles
- Reduced leaf surface area
- Reduced number of stomata and/or stomata located on underside of leaves
- Known to be very drought tolerant/drought adapted

Characteristics of high water use trees:

- Large and/or relatively soft leaves
- Large leaf surface area
- Known to be a "thirsty" tree or one that naturally occurs in ephemeral (e.g. *Melaleuca*) or moist soil environments (e.g. Rainforest species)

Note: Deciduous trees are highly variable and seasonal in their water use. They are not recommended for passively watered street trees due to their seasonal leaf drop and the stormwater blockage risk this presents.

Results Tree Pit Design Sizing Guide

The following table (Table 1) can be used to guide the design of passively watered tree pits in each climatic zone. Minimum and maximum treatment area (i.e. tree pit surface area) to catchment area ratios (TCARs) are provided. A tree pit with a catchment area that falls within this range will have optimised soil moisture conditions and meet the stormwater treatment objectives for that region. A tree pit with a low TCAR (e.g. 3%) will have a larger contributing catchment area than a tree pit with a higher TCAR (e.g. 10%).

Table 1. Passively watered tree pit design guide

Design Variables				Tree Pit Surface Area to Catchment Area Ratios											
Design	Wicking Zone Present	Soil Type	Tree Water Use (PET)	Cairns		Townsville		Mackay		Rockhampton		Sunshine Coast		Ipswich	
				Min	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
A	Yes	Sandy Loam	Low	N/A	N/A	4%	10%	N/A	N/A	3%	10%	4%	10%	3%	10%
B	Yes	Sandy Loam	High	N/A	N/A	4%	7%	N/A	N/A	3%	10%	4%	10%	3%	10%
C	Yes	Loamy Sand	Low	7%	10%	3%	8%	3%	10%	3%	10%	3%	10%	2%	10%
D	Yes	Loamy Sand	High	7%	10%	3%	7%	3%	10%	3%	10%	3%	10%	2%	10%
E	No	Sandy Loam	Low	N/A	N/A	4%	6%	N/A	N/A	3%	10%	4%	10%	3%	10%
F	No	Sandy Loam	High	N/A	N/A	4%	4%	N/A	N/A	3%	10%	4%	10%	3%	10%
G	No	Loamy Sand	Low	7%	10%	3%	5%	2%	10%	3%	10%	3%	10%	2%	10%
H	No	Loamy Sand	High	7%	10%	3%	4%	2%	10%	2%	10%	3%	10%	2%	10%

Key

N/A No suitable design size as system is too wet.
Sandy Loam 50 mm/hr saturated hydraulic conductivity (Ksat)
Loamy Sand 100mm/hr Ksat
Low 1.5 MUSIC PET Factor for low water use street trees (drought tolerant)
High 1.85 MUSIC PET Factor for high water use trees such as Melaleuca which will readily transpire water when available (can also show some drought tolerance)

Note

Tree pits were modelled with a size (i.e. surface area) up to 10% of their contributing catchment areas. 10% therefore represents the upper limit of modelling undertaken. In some locations larger TCAR's (ie smaller connected catchments) may be suitable but would require further modelling to avoid conditions that are "too dry".

Application of Tree pit Sizing Guide led by Landscape Requirements for Tree Size and required Soil Volume

The following tables, one for each climatic zone, provide guidance to designing optimised tree pits to meet the soil volume and soil moisture requirements of large, medium and small trees. The tree size, tree water use, soil type and presence or absence of a wicking zone variables provide design flexibility. It is noted that when designs fall outside of the optimal range (as mentioned in the tables) then more investigation may be required to find an appropriate solution.

Wet Tropics Cairns

Rainfall patterns in Cairns result in frequent wet conditions hence it is important for these tree pits to have freely draining soils and well-designed underdrainage. Due to the climatic conditions, it was found that systems with sandy loam soils with a hydraulic conductivity of 50mm/hr will result in soil moisture conditions which are considered too wet (i.e. soil moisture is greater than 80% for more than 5 days). Choosing a loamy sand type soil with a hydraulic conductivity of around 100mm/hr will result in optimal soil moisture conditions. Species which are adapted to growing in moist soil conditions could also be considered.

Cairns	Tree Height (m)	Soil Volume (m3)	Tree Water Use (1)	Soil Type (2)	Wicking Zone Present	Target Catchment Area Ratio		Optimal Catchment Area (3)	
						MAX	MIN	MAX (m2)	MIN(m2)
Large Tree	15	40	High	Sandy Loam	Yes	*No Suitable Design - Too Wet*			
					No	*No Suitable Design - Too Wet*			
				Loamy Sand	Yes	7%	10%	571	400
					No	7%	10%	571	400
			Low	Sandy Loam	Yes	*No Suitable Design - Too Wet*			
					No	*No Suitable Design - Too Wet*			
				Loamy Sand	Yes	7%	10%	571	400
					No	7%	10%	571	400
Medium Tree	12	20	High	Sandy Loam	Yes	*No Suitable Design - Too Wet*			
					No	*No Suitable Design - Too Wet*			
				Loamy Sand	Yes	7%	10%	286	200
					No	7%	10%	286	200
			Low	Sandy Loam	Yes	*No Suitable Design - Too Wet*			
					No	*No Suitable Design - Too Wet*			
				Loamy Sand	Yes	7%	10%	286	200
					No	7%	10%	286	200
Small Tree	7	12	High	Sandy Loam	Yes	*No Suitable Design - Too Wet*			
					No	*No Suitable Design - Too Wet*			
				Loamy Sand	Yes	7%	10%	171	120
					No	7%	10%	171	120
			Low	Sandy Loam	Yes	*No Suitable Design - Too Wet*			
					No	*No Suitable Design - Too Wet*			
				Loamy Sand	Yes	7%	10%	171	120
					No	7%	10%	171	120

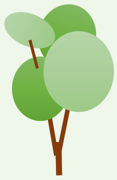
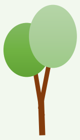
(1) Tree Water Use relates to the PET (Potential Evapotranspiration) Factor modelled being “High” = 1.85 MUSIC Scaling Factor; or “Low” = 1.5 MUSIC Scaling Factor

(2) “Sandy Loam” = 50mm/hr saturated hydraulic conductivity (KSat); “Loamy Sand”= 100mm/hr KSat

(3) 1m depth of soil within tree pit adopted to calculate tree pit surface area and stormwater catchment areas (min and max)

Dry Tropics Townsville

Townsville has a tropical climate but due to its geography it does not experience as much rainfall as elsewhere in the tropics. Winter is typically dry, clear and mild, while summer is hot and humid. It experiences a 6 month wet season from November to April and can be subject to cyclones (source BoM). Wicking zones are important for the street tree design in order to preserve water through the dry season.

Townsville	Tree Height (m)	Soil Volume (m3)	Tree Water Use (1)	Soil Type (2)	Wicking Zone Present	Target Catchment Area Ratio		Optimal Catchment Area (3)	
						MAX	MIN	MAX (m2)	MIN(m2)
Large Tree	15	40	High	Sandy Loam	Yes	4%	7%	1000	571
					No	4%	4%	1000	1000
				Loamy Sand	Yes	3%	7%	1333	571
					No	3%	4%	1333	1000
			Low	Sandy Loam	Yes	4%	10%	1000	400
					No	4%	6%	1000	667
				Loamy Sand	Yes	3%	8%	1333	500
					No	3%	5%	1333	800
Medium Tree	12	20	High	Sandy Loam	Yes	4%	7%	500	286
					No	4%	4%	500	500
				Loamy Sand	Yes	3%	7%	667	286
					No	3%	4%	667	500
			Low	Sandy Loam	Yes	4%	10%	500	200
					No	4%	6%	500	333
				Loamy Sand	Yes	3%	8%	667	250
					No	3%	5%	667	400
Small Tree	7	12	High	Sandy Loam	Yes	4%	7%	300	171
					No	4%	4%	300	300
				Loamy Sand	Yes	3%	7%	400	171
					No	3%	4%	400	300
			Low	Sandy Loam	Yes	4%	10%	300	120
					No	4%	6%	300	200
				Loamy Sand	Yes	3%	8%	400	150
					No	3%	5%	400	240

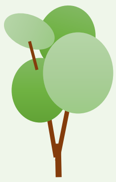
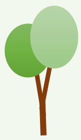
(1) Tree Water Use relates to the PET (Potential Evapotranspiration) Factor modelled being "High" = 1.85 MUSIC Scaling Factor; or "Low" = 1.5 MUSIC Scaling Factor

(2) "Sandy Loam" = 50mm/hr saturated hydraulic conductivity (KSat); "Loamy Sand"= 100mm/hr KSat

(3) 1m depth of soil within tree pit adopted to calculate tree pit surface area and stormwater catchment areas (min and max)

Central Coast North Mackay

Rainfall patterns in Mackay result in frequent wet conditions hence it is important for these tree pits to have freely draining soils and well-designed underdrainage. Due to the climatic conditions, it was found that systems with sandy loam soils with a hydraulic conductivity of 50mm/hr will result in soil moisture conditions which are considered too wet (i.e. soil moisture is greater than 80% for more than 5 days). Choosing a loamy sand type soil with a hydraulic conductivity of around 100mm/hr will result in optimal soil moisture conditions. Species which are adapted to growing in moist soil conditions could also be considered.

Mackay	Tree Height (m)	Soil Volume (m3)	Tree Water Use (1)	Soil Type (2)	Wicking Zone Present	Target Catchment Area Ratio		Optimal Catchment Area (3)	
						MAX	MIN	MAX (m2)	MIN(m2)
Large Tree 	15	40	High	Sandy Loam	Yes	*No Suitable Design - Too Wet*			
					No	*No Suitable Design - Too Wet*			
				Loamy Sand	Yes	3%	10%	1333	400
					No	2%	10%	2000	400
			Low	Sandy Loam	Yes	*No Suitable Design - Too Wet*			
					No	*No Suitable Design - Too Wet*			
				Loamy Sand	Yes	3%	10%	1333	400
					No	2%	10%	2000	400
Medium Tree 	12	20	High	Sandy Loam	Yes	*No Suitable Design - Too Wet*			
					No	*No Suitable Design - Too Wet*			
				Loamy Sand	Yes	3%	10%	667	200
					No	2%	10%	1000	200
			Low	Sandy Loam	Yes	*No Suitable Design - Too Wet*			
					No	*No Suitable Design - Too Wet*			
				Loamy Sand	Yes	3%	10%	667	200
					No	2%	10%	1000	200
Small Tree 	7	12	High	Sandy Loam	Yes	*No Suitable Design - Too Wet*			
					No	*No Suitable Design - Too Wet*			
				Loamy Sand	Yes	3%	10%	400	120
					No	2%	10%	600	120
			Low	Sandy Loam	Yes	*No Suitable Design - Too Wet*			
					No	*No Suitable Design - Too Wet*			
				Loamy Sand	Yes	3%	10%	400	120
					No	2%	10%	600	120

(1) Tree Water Use relates to the PET (Potential Evapotranspiration) Factor modelled being "High" = 1.85 MUSIC Scaling Factor; or "Low" = 1.5 MUSIC Scaling Factor

(2) "Sandy Loam" = 50mm/hr saturated hydraulic conductivity (KSat); "Loamy Sand"= 100mm/hr KSat

(3) 1m depth of soil within tree pit adopted to calculate tree pit surface area and stormwater catchment areas (min and max)

Central Coast South Rockhampton

Rockhampton Regional Council

Rockhampton's average annual rainfall is a little over 800mm. Rainfall averages suggest a distinct wet and dry season, with the wet generally December to March and the dry June to September (source BoM).

Rocky	Tree Height (m)	Soil Volume (m3)	Tree Water Use (1)	Soil Type (2)	Wicking Zone Present	Target Catchment Area Ratio		Optimal Catchment Area (3)	
						MAX	MIN	MAX (m2)	MIN(m2)
Large Tree	15	40	High	Sandy Loam	Yes	3%	10%	1333	400
					No	3%	10%	1333	400
				Loamy Sand	Yes	3%	10%	1333	400
					No	2%	10%	2000	400
			Low	Sandy Loam	Yes	3%	10%	1333	400
					No	3%	10%	1333	400
				Loamy Sand	Yes	3%	10%	1333	400
					No	3%	10%	1333	400
Medium Tree	12	20	High	Sandy Loam	Yes	3%	10%	667	200
					No	3%	10%	667	200
				Loamy Sand	Yes	3%	10%	667	200
					No	2%	10%	1000	200
			Low	Sandy Loam	Yes	3%	10%	667	200
					No	3%	10%	667	200
				Loamy Sand	Yes	3%	10%	667	200
					No	3%	10%	667	200
Small Tree	7	12	High	Sandy Loam	Yes	3%	10%	400	120
					No	3%	10%	400	120
				Loamy Sand	Yes	3%	10%	400	120
					No	2%	10%	600	120
			Low	Sandy Loam	Yes	3%	10%	400	120
					No	3%	10%	400	120
				Loamy Sand	Yes	3%	10%	400	120
					No	3%	10%	400	120

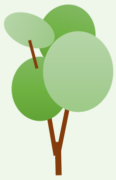
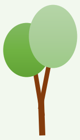
(1) Tree Water Use relates to the PET (Potential Evapotranspiration) Factor modelled being "High" = 1.85 MUSIC Scaling Factor; or "Low" = 1.5 MUSIC Scaling Factor

(2) "Sandy Loam" = 50mm/hr saturated hydraulic conductivity (KSat); "Loamy Sand"= 100mm/hr KSat

(3) 1m depth of soil within tree pit adopted to calculate tree pit surface area and stormwater catchment areas (min and max)

SEQ North Sunshine Coast

The Sunshine Coast has an average of 1450mm of rain throughout the year. The region experiences higher rainfall in the summer months and a drier climate in the winter.

SC	Tree Height (m)	Soil Volume (m3)	Tree Water Use (1)	Soil Type (2)	Wicking Zone Present	Target Catchment Area Ratio		Optimal Catchment Area (3)	
						MAX	MIN	MAX (m2)	MIN(m2)
Large Tree	15	40	High	Sandy Loam	Yes	4%	10%	1000	400
					No	4%	10%	1000	400
				Loamy Sand	Yes	3%	10%	1333	400
					No	3%	10%	1333	400
			Low	Sandy Loam	Yes	4%	10%	1000	400
					No	4%	10%	1000	400
				Loamy Sand	Yes	3%	10%	1333	400
					No	3%	10%	1333	400
Medium Tree	12	20	High	Sandy Loam	Yes	4%	10%	500	200
					No	4%	10%	500	200
				Loamy Sand	Yes	3%	10%	667	200
					No	3%	10%	667	200
			Low	Sandy Loam	Yes	4%	10%	500	200
					No	4%	10%	500	200
				Loamy Sand	Yes	3%	10%	667	200
					No	3%	10%	667	200
Small Tree	7	12	High	Sandy Loam	Yes	4%	10%	300	120
					No	4%	10%	300	120
				Loamy Sand	Yes	3%	10%	400	120
					No	3%	10%	400	120
			Low	Sandy Loam	Yes	4%	10%	300	120
					No	4%	10%	300	120
				Loamy Sand	Yes	3%	10%	400	120
					No	3%	10%	400	120

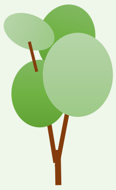
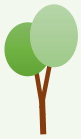
(1) Tree Water Use relates to the PET (Potential Evapotranspiration) Factor modelled being “High” = 1.85 MUSIC Scaling Factor; or “Low” = 1.5 MUSIC Scaling Factor

(2) “Sandy Loam” = 50mm/hr saturated hydraulic conductivity (KSat); “Loamy Sand”= 100mm/hr KSat

(3) 1m depth of soil within tree pit adopted to calculate tree pit surface area and stormwater catchment areas (min and max)

SEQ West Ipswich

On average, Ipswich has approximately 880mm of rain a year. This is distributed over the year with the wetter months occurring over the summer and the drier months over winter.

Ipswich	Tree Height (m)	Soil Volume (m3)	Tree Water Use (1)	Soil Type (2)	Wicking Zone Present	Target Catchment Area Ratio		Optimal Catchment Area (3)	
						MAX	MIN	MAX (m2)	MIN(m2)
Large Tree 	15	40	High	Sandy Loam	Yes	3%	10%	1333	400
					No	3%	10%	1333	400
				Loamy Sand	Yes	2%	10%	2000	400
					No	2%	10%	2000	400
			Low	Sandy Loam	Yes	3%	10%	1333	400
					No	3%	10%	1333	400
				Loamy Sand	Yes	2%	10%	2000	400
					No	2%	10%	2000	400
Medium Tree 	12	20	High	Sandy Loam	Yes	3%	10%	667	200
					No	3%	10%	667	200
				Loamy Sand	Yes	2%	10%	1000	200
					No	2%	10%	1000	200
			Low	Sandy Loam	Yes	3%	10%	667	200
					No	3%	10%	667	200
				Loamy Sand	Yes	2%	10%	1000	200
					No	2%	10%	1000	200
Small Tree 	7	12	High	Sandy Loam	Yes	3%	10%	400	120
					No	3%	10%	400	120
				Loamy Sand	Yes	2%	10%	600	120
					No	2%	10%	600	120
			Low	Sandy Loam	Yes	3%	10%	400	120
					No	3%	10%	400	120
				Loamy Sand	Yes	2%	10%	600	120
					No	2%	10%	600	120

(1) Tree Water Use relates to the PET (Potential Evapotranspiration) Factor modelled being “High” = 1.85 MUSIC Scaling Factor; or “Low” = 1.5 MUSIC Scaling Factor

(2) “Sandy Loam” = 50mm/hr saturated hydraulic conductivity (KSat); “Loamy Sand”= 100mm/hr KSat

(3) 1m depth of soil within tree pit adopted to calculate tree pit surface area and stormwater catchment areas (min and max)

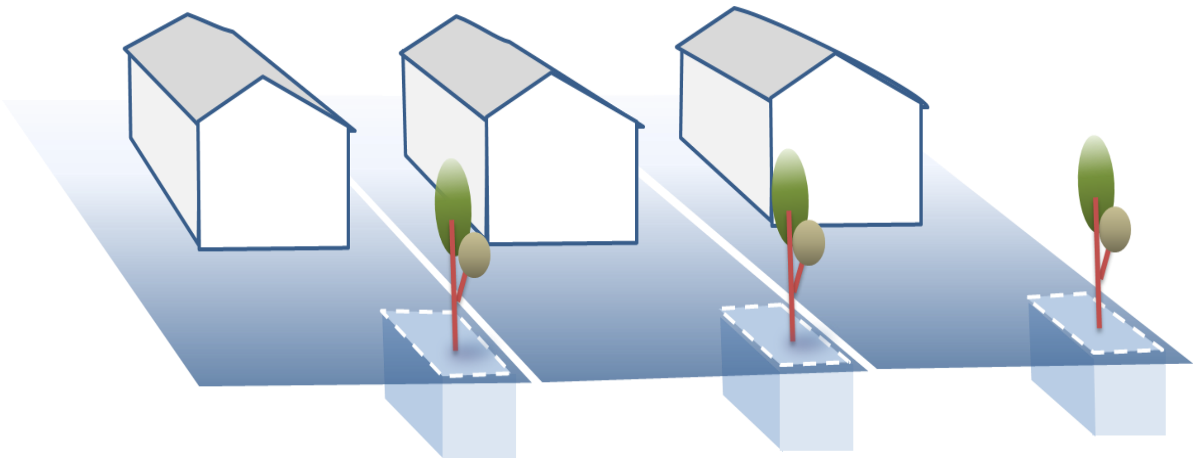
Worked Example 01 – Passively watered street trees

Dylan, a WSUD consultant, was designing a green infrastructure strategy for a new residential development in Townsville. The vision for the development was to create shaded tree lined streets. Working with the project landscape architects, two medium sized street tree species were selected. These tree species were very hardy and drought tolerant and as such considered as being low water use species. A quality sandy loam topsoil was locally available and testing was conducted to ensure the soil met the required characteristics (see Table 2). A minimum soil volume of 20m^3 per tree pit was required, for the selected tree species, to ensure tree health and for the trees to reach their full height and shade coverage potential. The design soil depth was 1m and underdrainage could readily be connected to the proposed stormwater pipe network. Based on the recommended treatment area to catchment area ratios (Table 2) catchment areas of 200m^2 (with wicking zone) up to 500m^2 (with or without wicking zone) per tree would provide good soil moisture levels and achieve the stormwater pollutant load reduction objectives. This equated to 20 - 50 passively watered trees per hectare.

Working with the project landscape architects, urban designers and civil engineers, the trees were incorporated early into the urban layout to ensure space was available and minimised conflicts with underground services, street lighting and foot paths. Road grading and side entry pit locations were coordinated to enable the optimal distribution of road catchment area to the street trees.

The street trees were modelled in MUSIC and demonstrated performance outcomes that met the required stormwater pollutant load objectives such that no other treatment systems were required for stormwater quality management.

The outcome meant that the future community could enjoy the benefits of shaded tree lined streets (including increased property prices), the developer who was investing in street trees regardless didn't need to invest in the design and delivery of alternative stormwater treatment systems and the Council had confidence in the long-term success of the street trees and the protection of the receiving environment.



What is a Wicking Bed?

A wicking bed is a vegetated system that has a reservoir of water (i.e. artificial aquifer) at the base from which water is draw upwards like a wick to the soil layer above. Wicking beds receive stormwater from direct rainfall, and from external catchments, directly into the subsurface storage. Stormwater runoff receives pre-treatment for litter and sediments (e.g. through porous pavement or litter baskets) before being directed to the subsurface wicking zone to replenish the aquifer. The plants access the water by using the natural process of soil capillary rise, driven by evapotranspiration, to draw water reserves held in the aquifer to the active root zone. As the plants remove water from the soil it is replaced by water replenished from the storage below by capillary action thereby ensuring optimal soil moisture conditions for healthy growth. Excess flows, greater than the storage capacity of the wicking layer, overflow at the top of the wicking layer to avoid saturation of the topsoil. Figure 5 provides a typical cross section through a turf wicking bed.

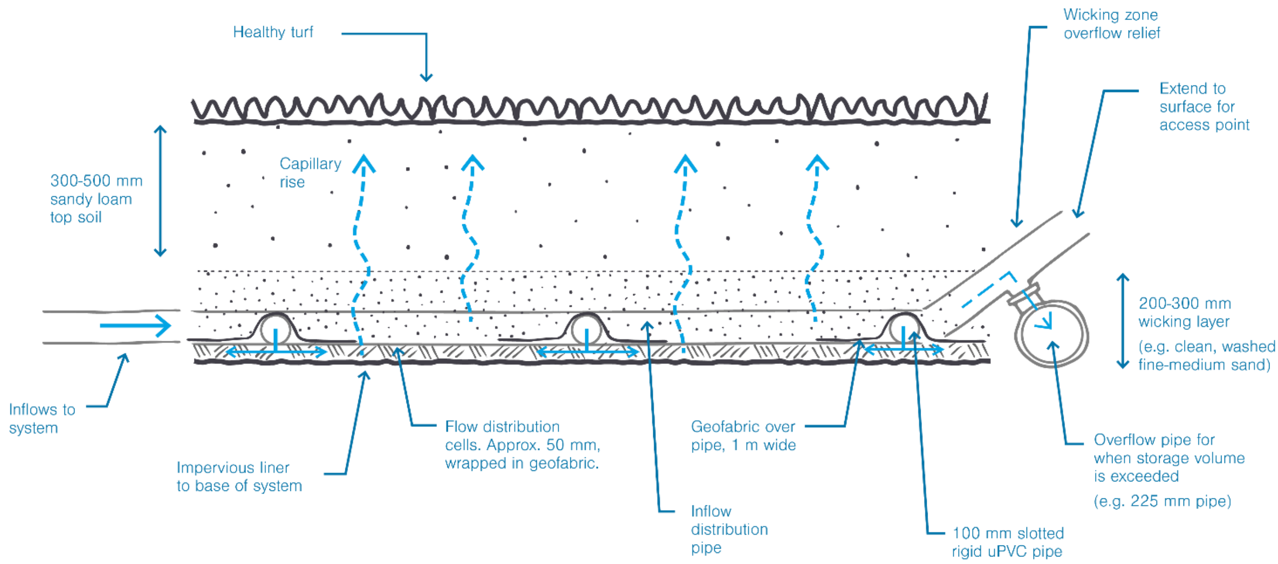


FIGURE 5. TYPICAL CROSS SECTION THROUGH A WICKING BED PASSIVELY IRRIGATING A TURF OPEN SPACE AREA

Modelling Wicking Beds

Method – how do we know what design configurations will work in each climatic zone?

Detailed modelling was undertaken to inform the design of wicking beds. This included:

- Rainfall Analysis - to confirm the most appropriate rainfall data set for each region
- Soil Moisture Modelling - evapotranspiration modelling and soil moisture data analysis to determine to occurrence of overly saturated conditions (too wet) and identification of dry spells below wilting point (too dry)
- MUSIC Modelling - water quality modelling to demonstrate stormwater pollutant removal performance
- Wicking Zone Storage Volume and Reliability Modelling – to determine the volume of water within the wicking zone storage required to achieve a sufficient (>70%) reliability of supply

For each climatic zone, the following scenarios were modelled:

- 1 x water use levels (PET = 1.0; indicative of turf or groundcover plants)
- 1 x soil types (loamy sand; 100mm/hr)
- 3 x wicking bed storage volumes - based on a wicking bed depths of 100mm (small); 250mm (medium) and 400mm (deep) and a porosity that falls within the range of sand (relatively low porosity of 0.35) and proprietary wicking storage cells (relatively high porosity of 0.95) (Figure 6).

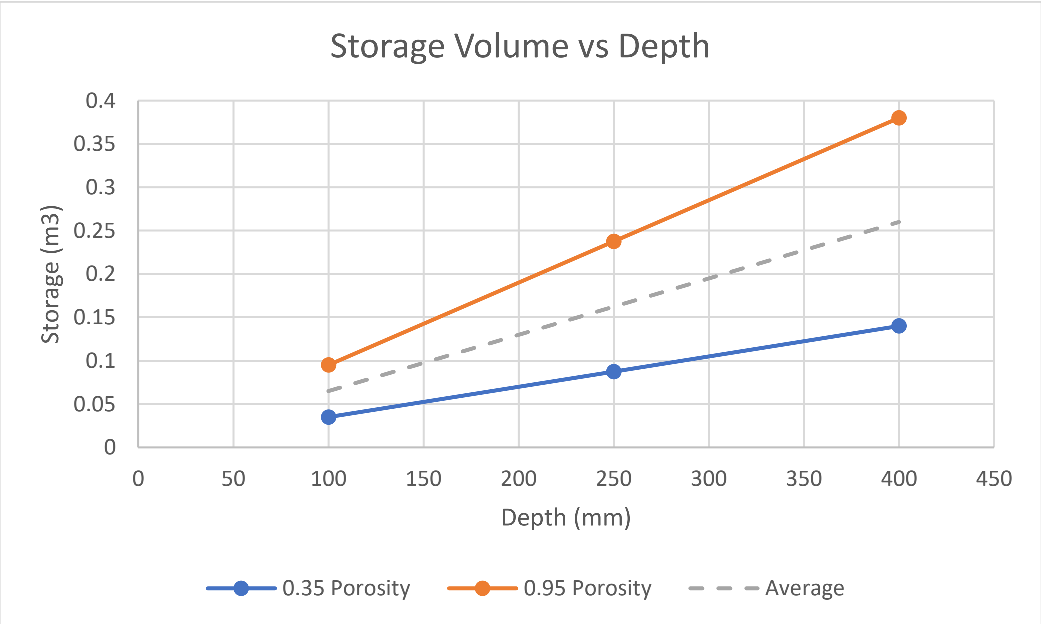


FIGURE 6. RELATIONSHIP BETWEEN STORAGE VOLUME AND WICKING ZONE DEPTH AND POROSITY

Modelled results for Wicking Lawn

Storage – Source – Demand

The driver for designing a turf wicking lawn is to provide a reliable source of non-potable water for irrigation, resulting in healthy turf and using stormwater as a resource. Wicking lawns are generally suitable for sites where quality open space is desired for aesthetics and/or functionality (e.g. sportsfields). As such the area is often determined by landscape and open space design processes rather than the achievement of a target soil volume (as is the case with trees) or stormwater treatment outcomes (as with bioretention systems). The area of wicking lawn is typically large compared to the contributing catchment area. The catchment area to ensure a reliable source of irrigation for these systems (i.e. >70% reliability) can be as little as 2 times the surface area of the lawn (Figure 7). The design for turf wicking lawns is scalable and can be applied to large sports fields through to small podium landscape areas. When designing wicking beds, consideration needs to be given to the wicking zone storage volume, the source of the water (i.e. catchment size) and the water demand of the turf.

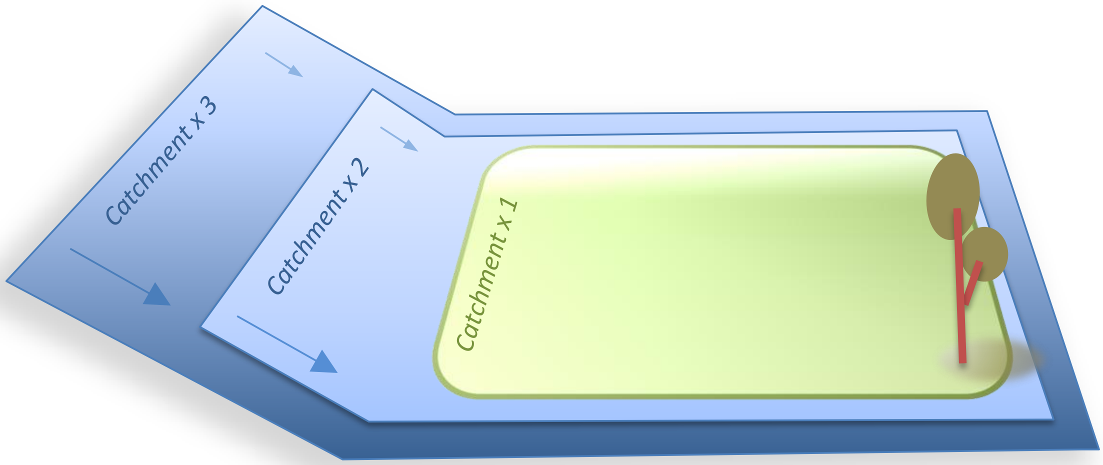


FIGURE 7. ILLUSTRATION OF TYPICAL WICKING LAWN AREA IN COMPARISON TO CATCHMENT AREA

Storage

The storage zone or aquifer for the wicking lawn extends under the full surface area of the system, such that all turf can have equal access to the soil moisture stores. The depth of the storage zone and the porosity of the wicking media will determine the volume of water that can be stored. The maximum depth of the storage zone is determined by the capillary rise or wicking ability of the media while minimum depth is required to incorporate a flow distribution network. Flow distribution is designed to ensure even top up of the storage zone and effective overflow once the storage is full.

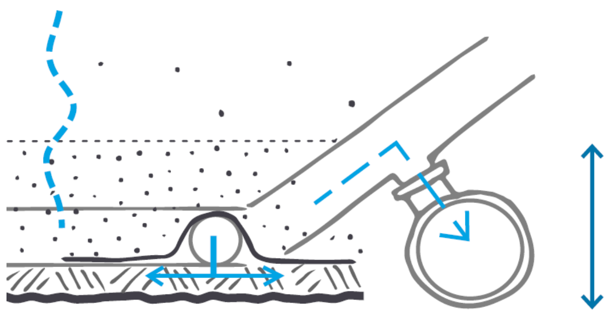


FIGURE 8. WICKING BED OUTLET DETAIL

Source

Flows from external catchments are directed to pre-treatment, for litter and sediment removal, and then piped directly to the wicking zone aquifer. To enable regular top-up of the wicking bed storage, it is important that runoff from small (and more frequent) rainfall events reaches the storage zone. This is essential to ensure the wicking bed is operating at its optimal reliability. The area of catchment connected to the wicking lawn will also influence the reliability of the system. Flows greater than the 1 EY should bypass the wicking system, so that the wicking bed flow distribution network does not need to be oversized.

While large catchment areas will increase the volume of runoff directed to the system, a portion of this flow will be lost by overtopping of the aquifer when full. Site topography will determine the natural catchment areas of a wicking lawn however there will be additional opportunities to direct flow from adjacent impervious surfaces and roofs which allow a designer to optimise the catchment area of a system.

Demand

The maximum irrigation demand for a lawn is determined by several factors including:

Climatic Conditions - Temperature, Humidity, Wind, Sunshine

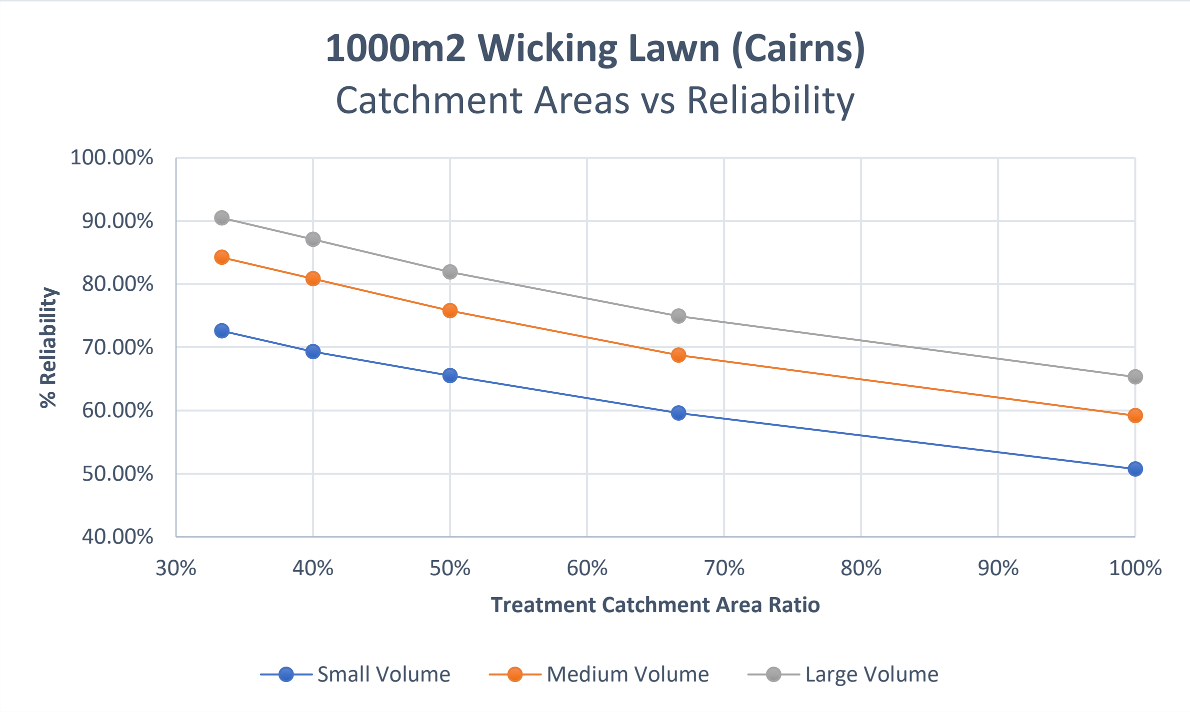
Crop Factor – Volume of water required for a specific species to grow. This can vary through a season and different growth phases of a plant.

Surface Area – Larger wicking lawns will have a higher demand.

Wicking lawns provide an effective method of irrigation for public open spaces as turf can access water while the space is occupied during the day. There is physical separation between people using the space and the stormwater such that it is a very safe form of stormwater harvesting. Delivery of irrigation via soil moisture is also very efficient, as there is no loss due to evaporation of aerial spray. In addition, the turf will not be over irrigated as it will use the volume of water required.

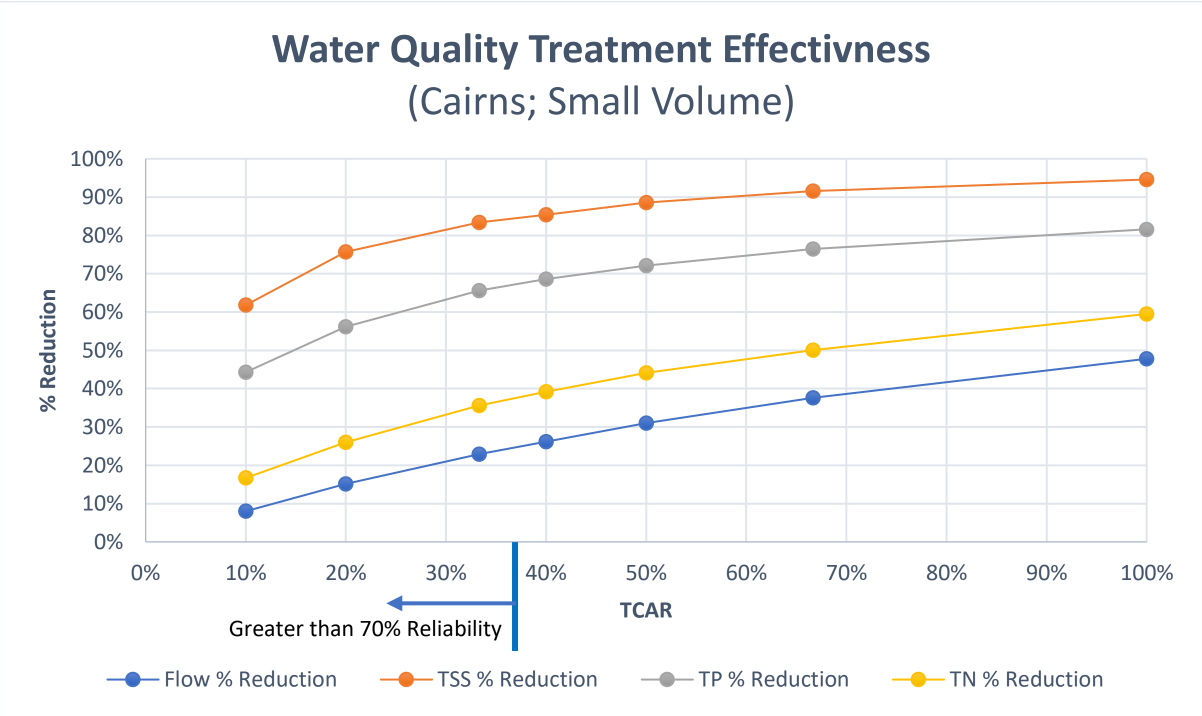
The following graphs, prepared for each climatic zone, can be used to guide the design of wicking lawns. Graphs include stormwater treatment performance at various TCARs and wicking bed volumes; and reliability at various TCARs and wicking bed volumes.

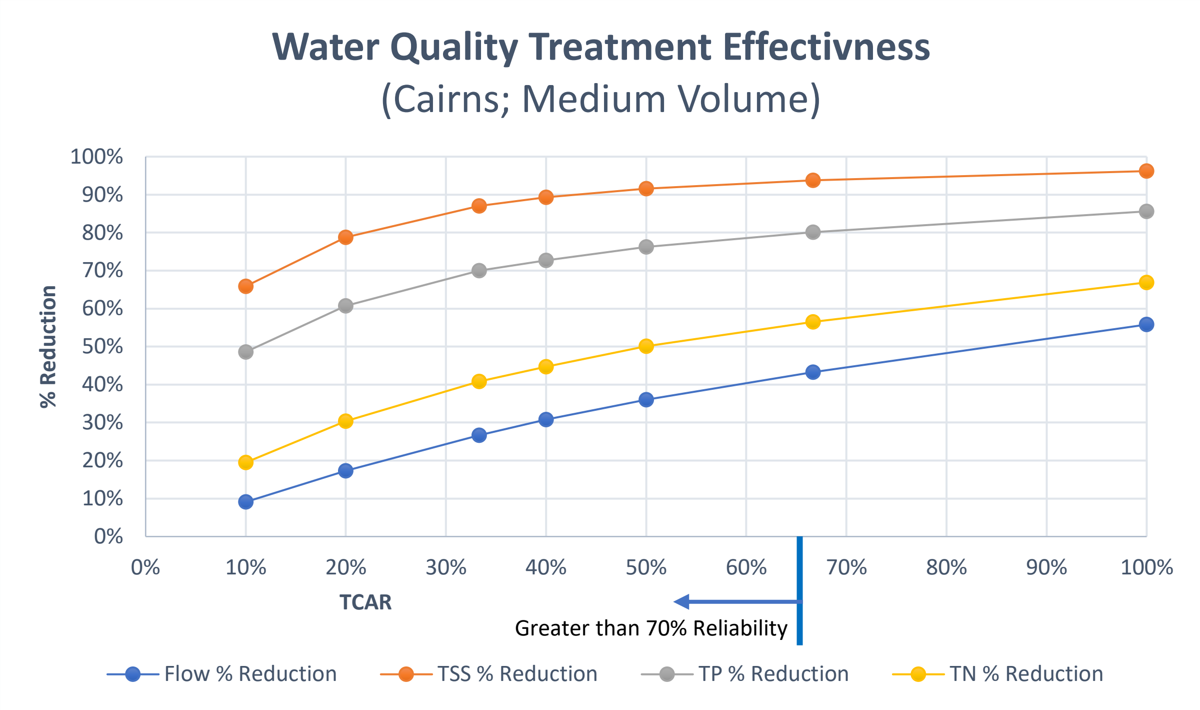
Reliability



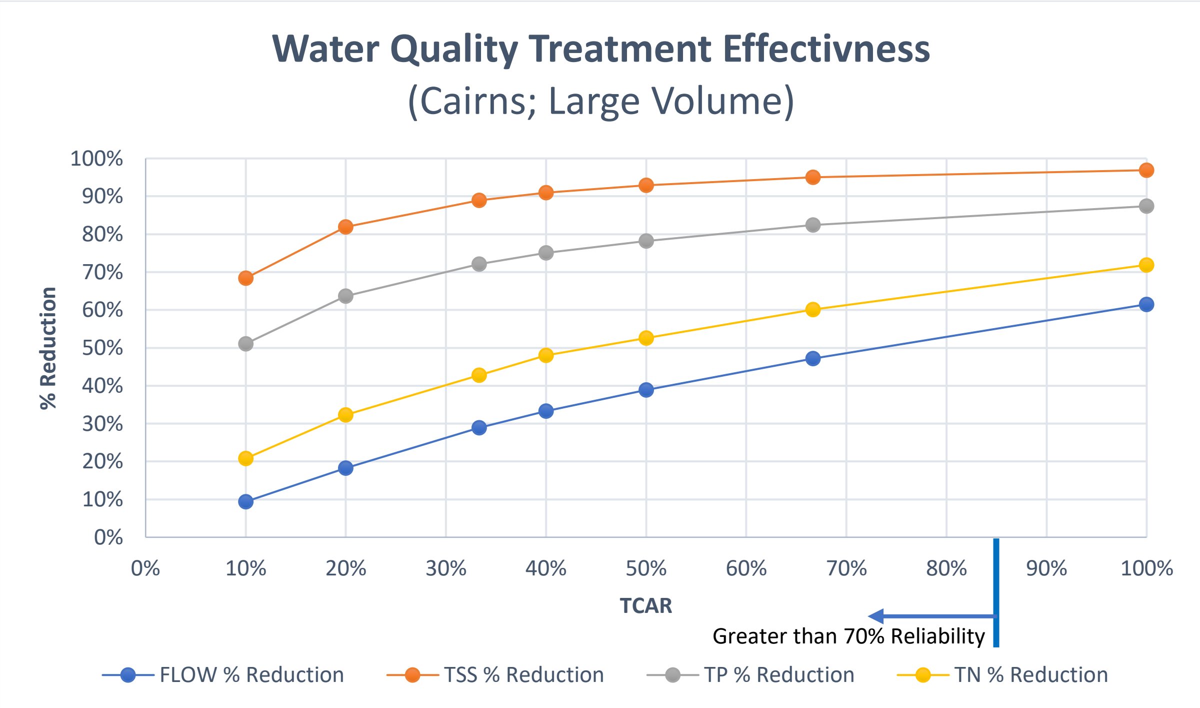
Treatment

(Cairns – Water Quality Objectives as per SPP 2017; TSS=80%, TP=65% & TN=40%)





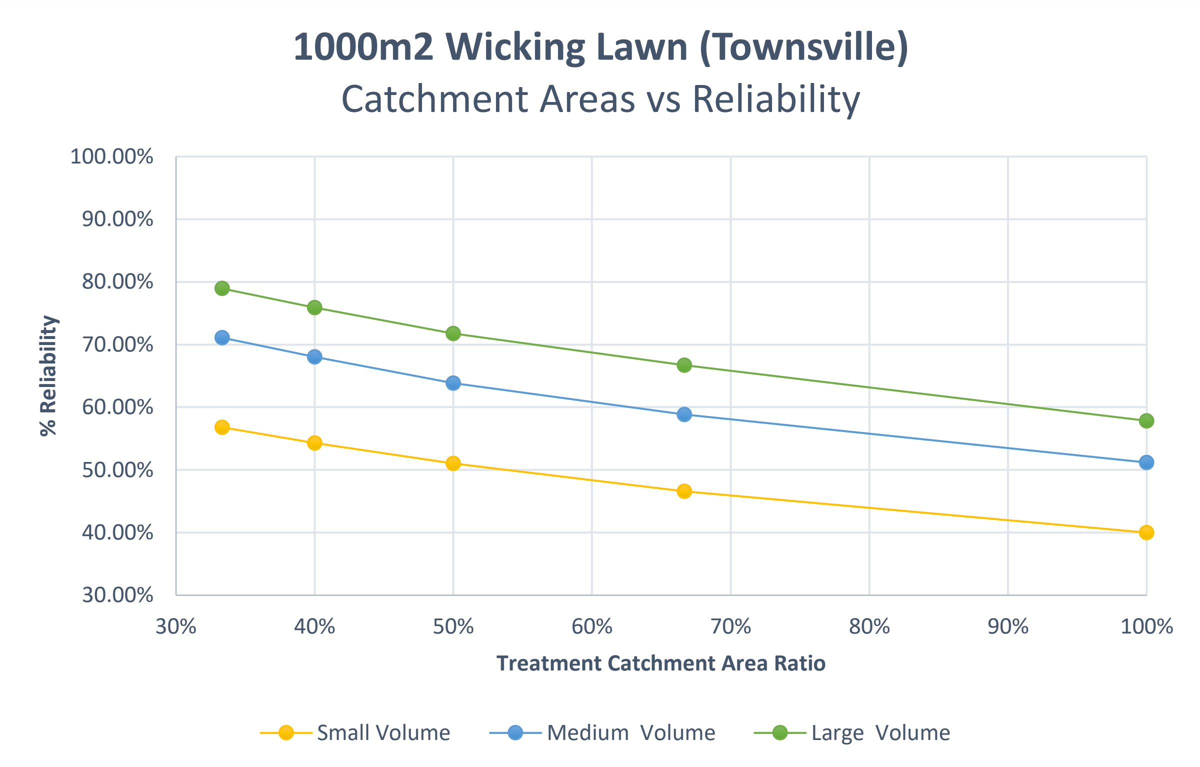
Water Quality Treatment Effectivness
(Cairns; Medium Volume)
% Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
TCAR
Greater than 70% Reliability
Flow % Reduction
TSS % Reduction
TP % Reduction
TN % Reduction



Water Quality Treatment Effectivness
(Cairns; Large Volume)
% Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
TCAR
Greater than 70% Reliability
FLOW % Reduction
TSS % Reduction
TP % Reduction
TN % Reduction

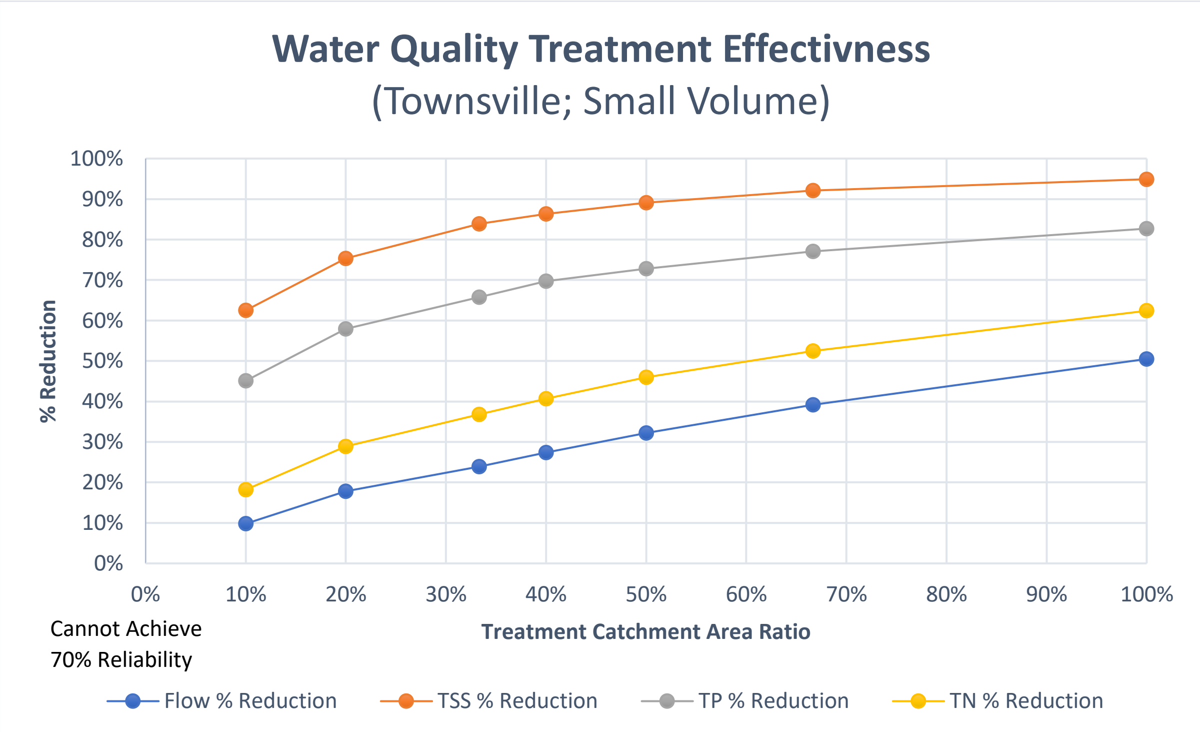
Dry Tropics Townsville

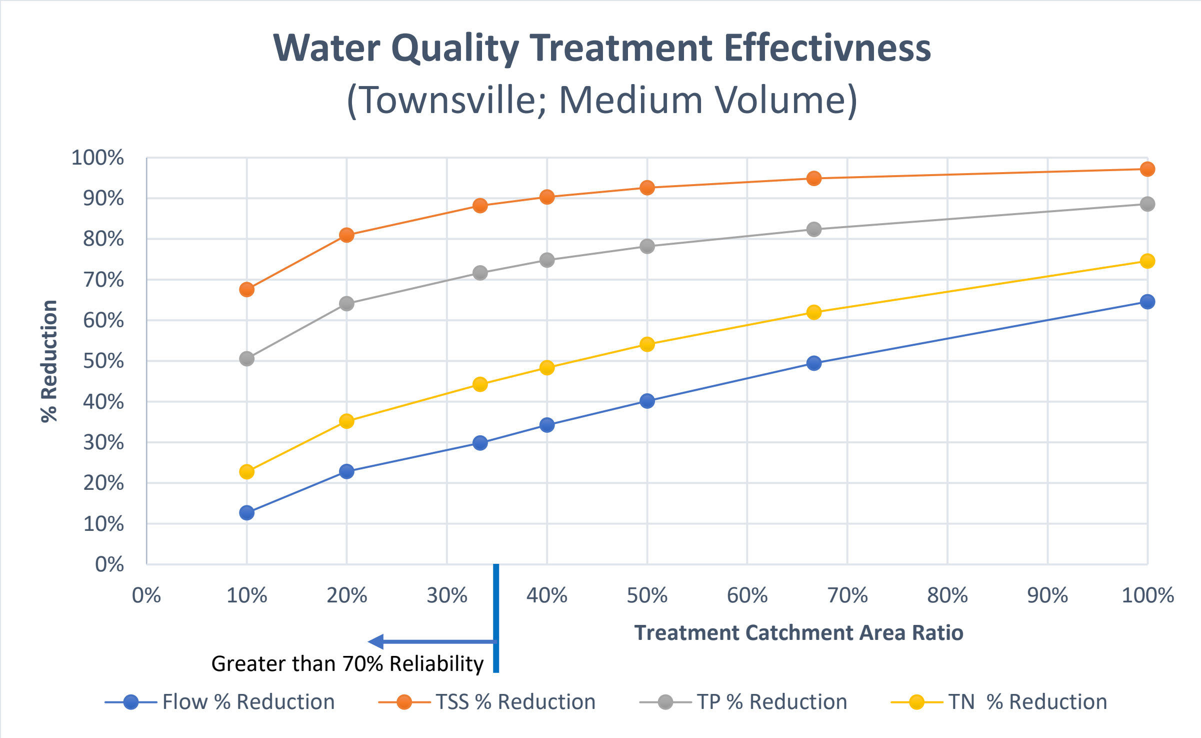
Reliability

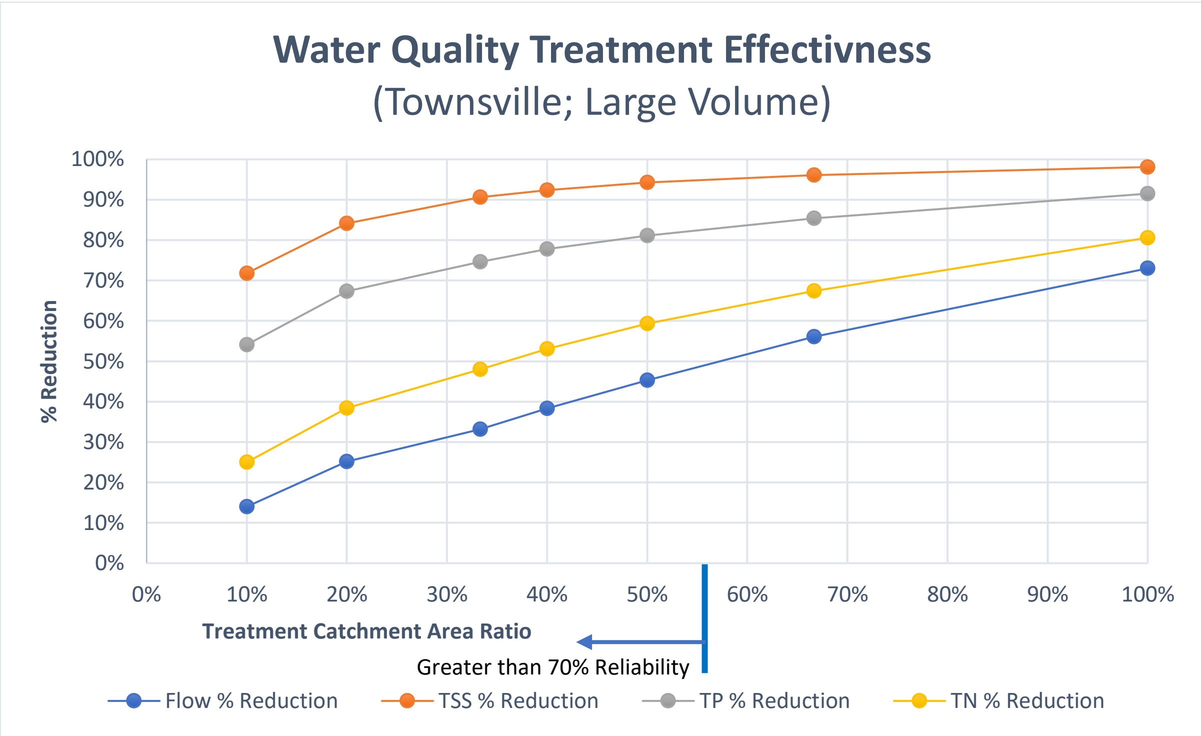


Treatment

(Townsville – Water Quality Objectives as per SPP 2017; TSS=80%, TP=65% & TN=40%)

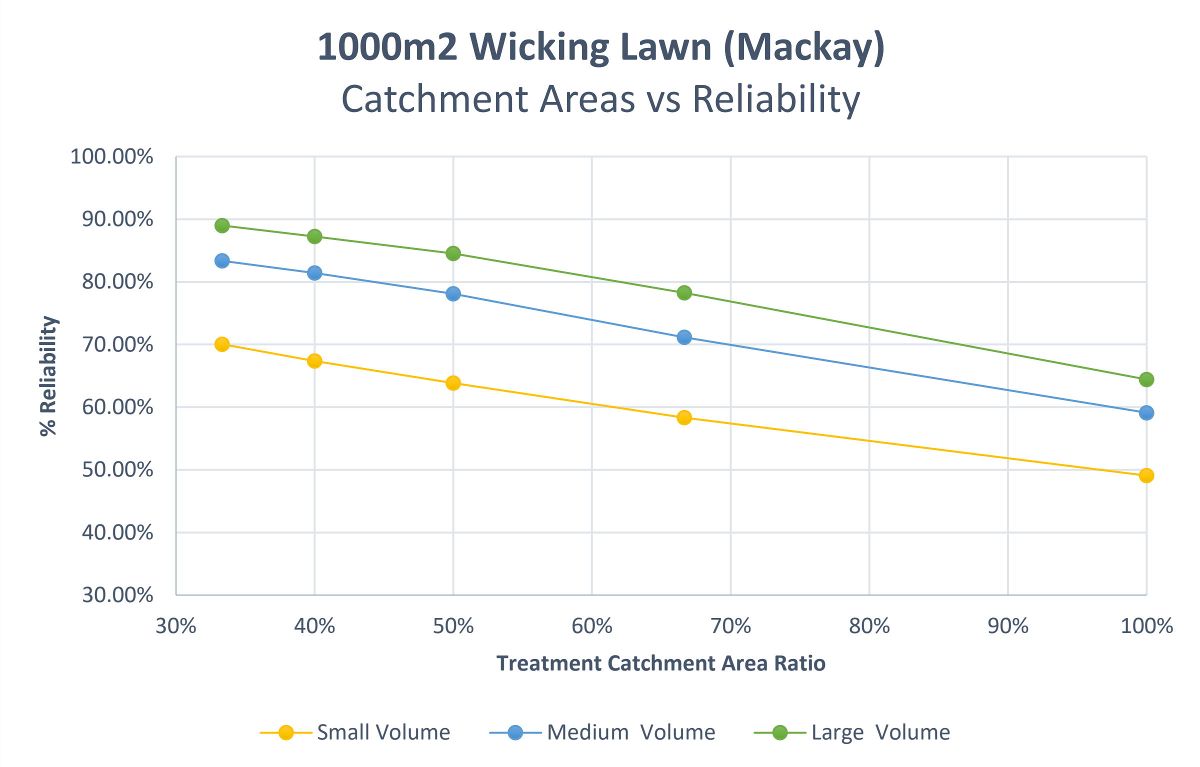



Water Quality Treatment Effectivness
(Townsville; Medium Volume)
% Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
Treatment Catchment Area Ratio
Greater than 70% Reliability
Flow % Reduction
TSS % Reduction
TP % Reduction
TN % Reduction


Water Quality Treatment Effectivness
(Townsville; Large Volume)
% Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
Treatment Catchment Area Ratio
Greater than 70% Reliability
Flow % Reduction
TSS % Reduction
TP % Reduction
TN % Reduction

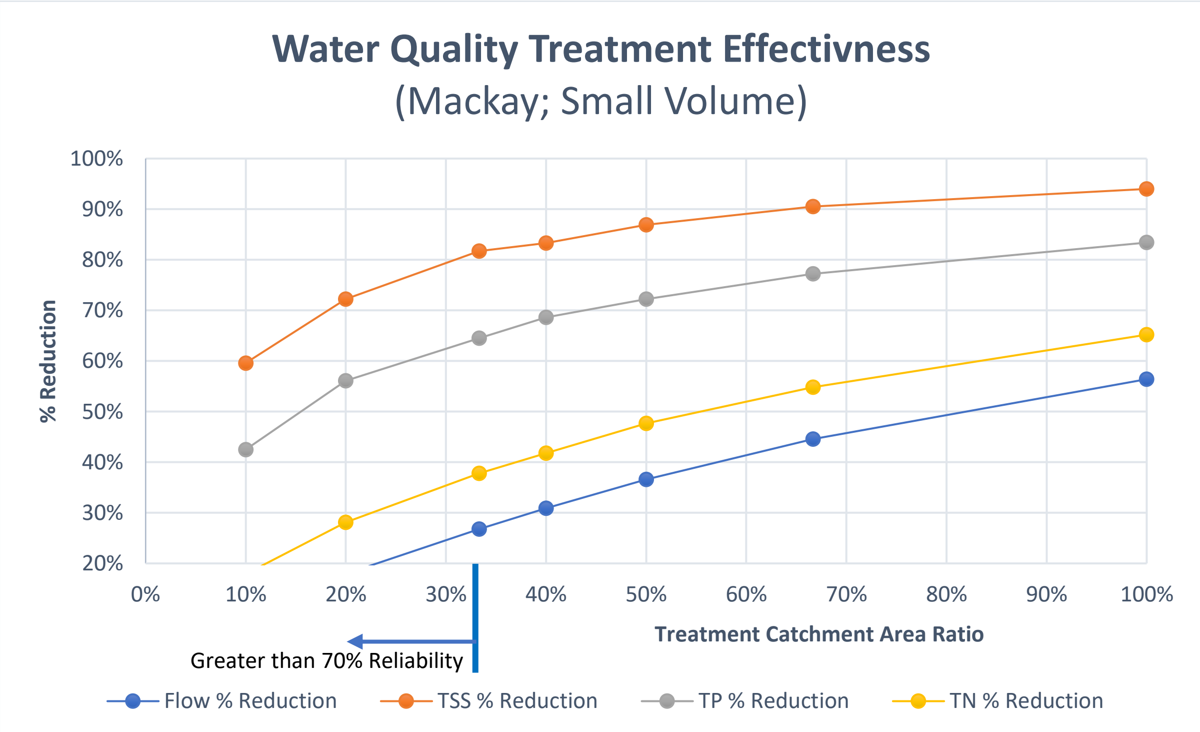
Central Coast North Mackay

Reliability



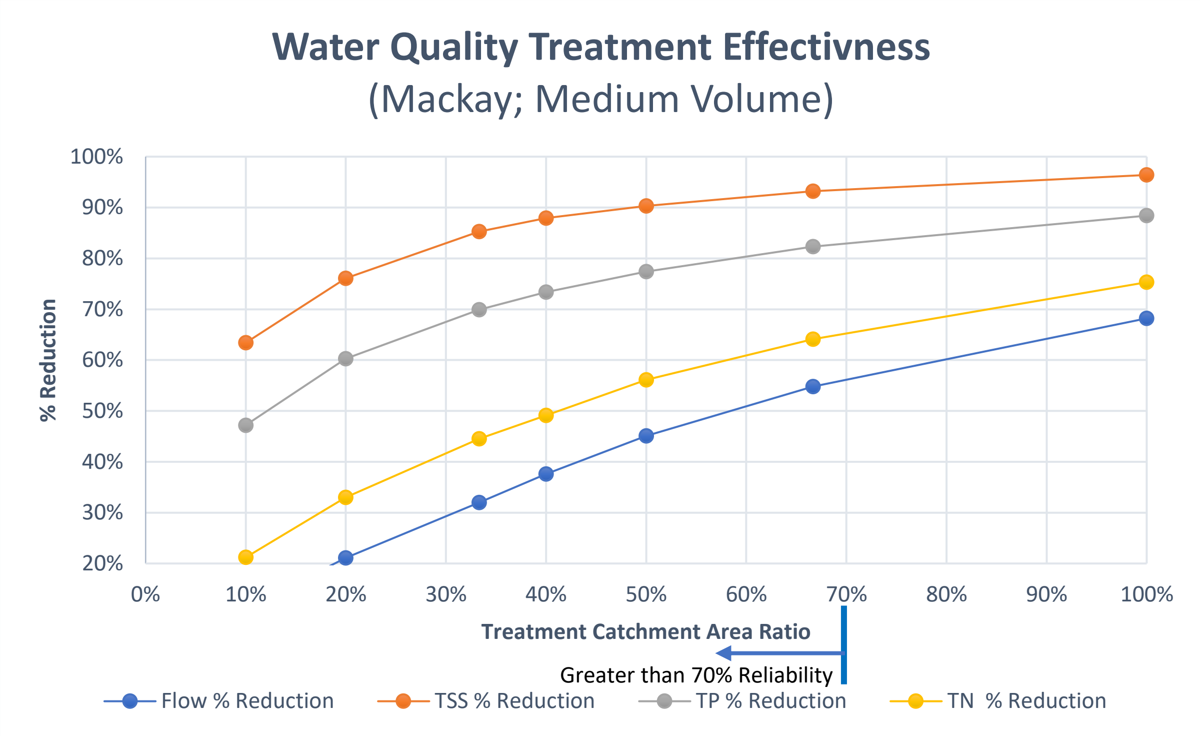
Treatment

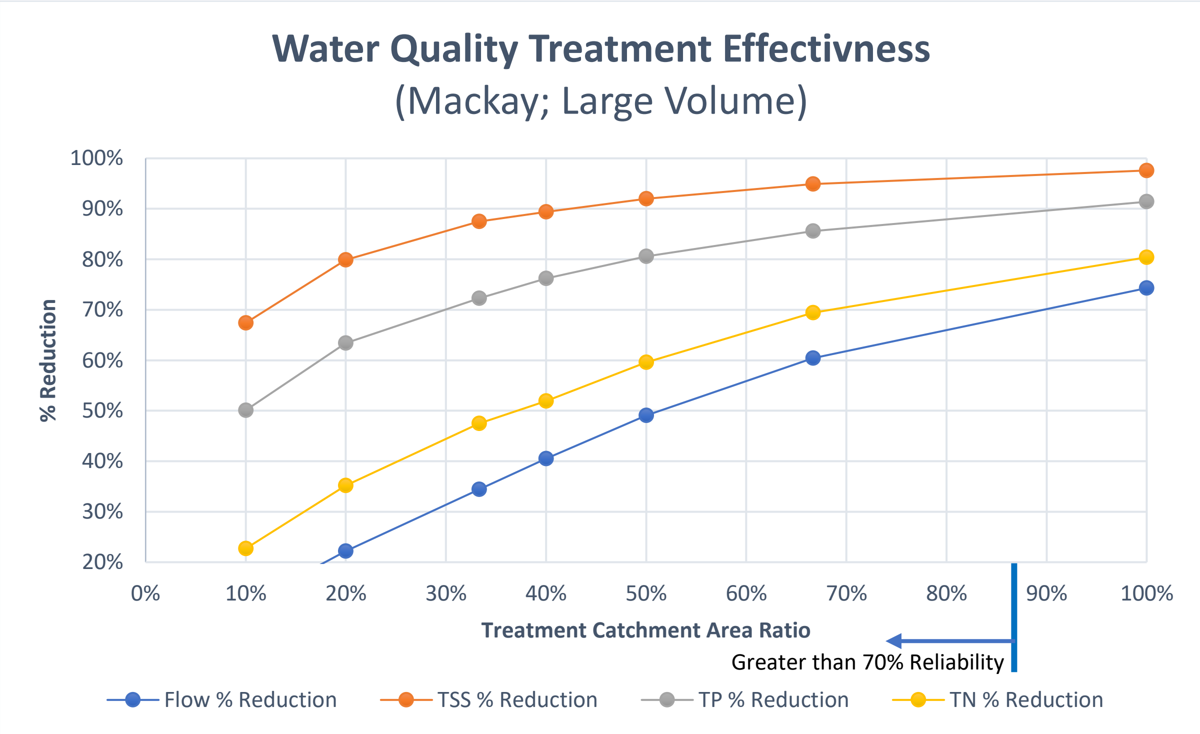
(Mackay – Water Quality Objectives as per SPP 2017; TSS=75%, TP=60% & TN=35%)



E2DESIGNLAB

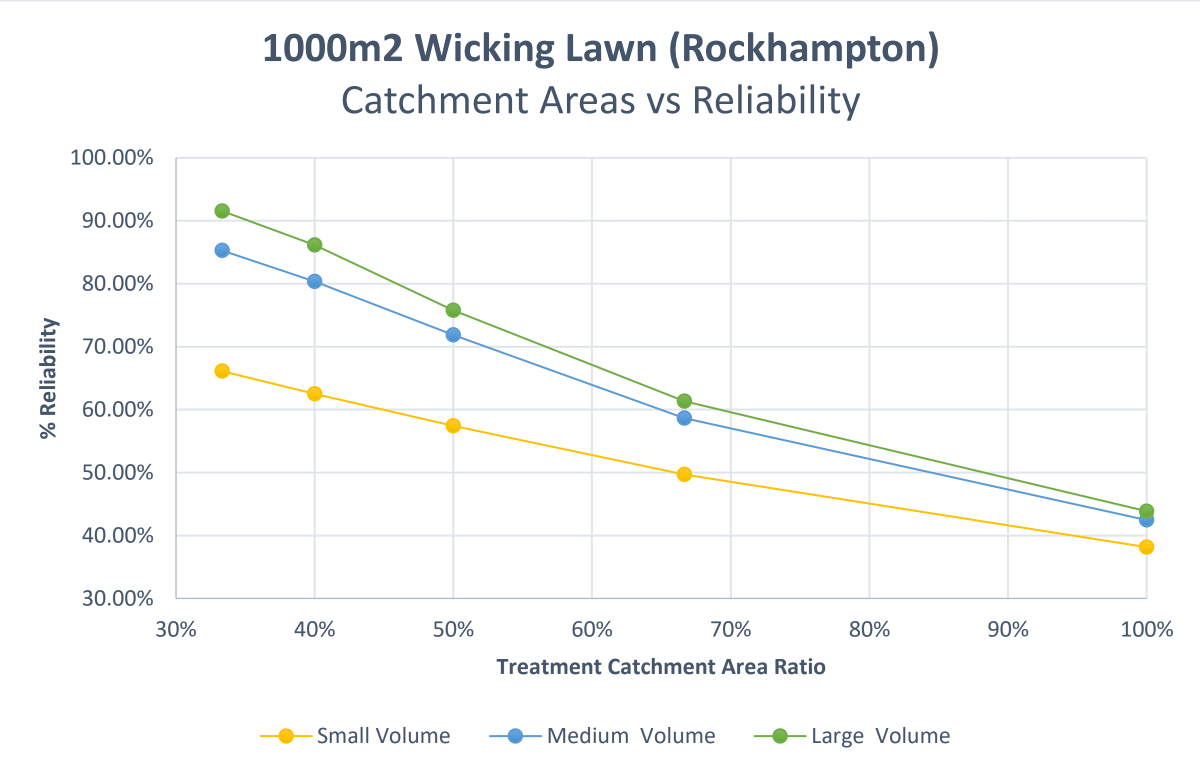
water by design
an initiative of
Healthy land & water


Water Quality Treatment Effectivness
(Mackay; Medium Volume)
100%
90%
80%
70%
60%
50%
40%
30%
20%
% Reduction
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Treatment Catchment Area Ratio
Greater than 70% Reliability
Flow % Reduction
TSS % Reduction
TP % Reduction
TN % Reduction


Water Quality Treatment Effectivness
(Mackay; Large Volume)
100%
90%
80%
70%
60%
50%
40%
30%
20%
% Reduction
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Treatment Catchment Area Ratio
Greater than 70% Reliability
Flow % Reduction
TSS % Reduction
TP % Reduction
TN % Reduction

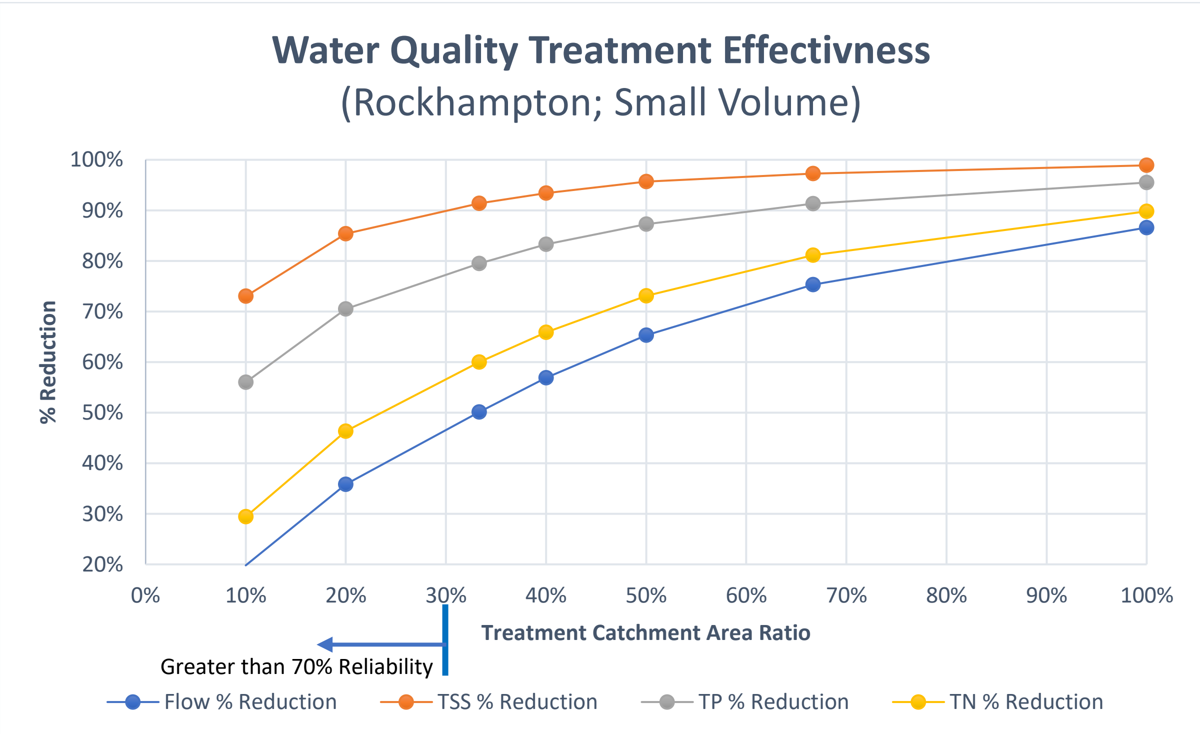
Central Coast South Rockhampton

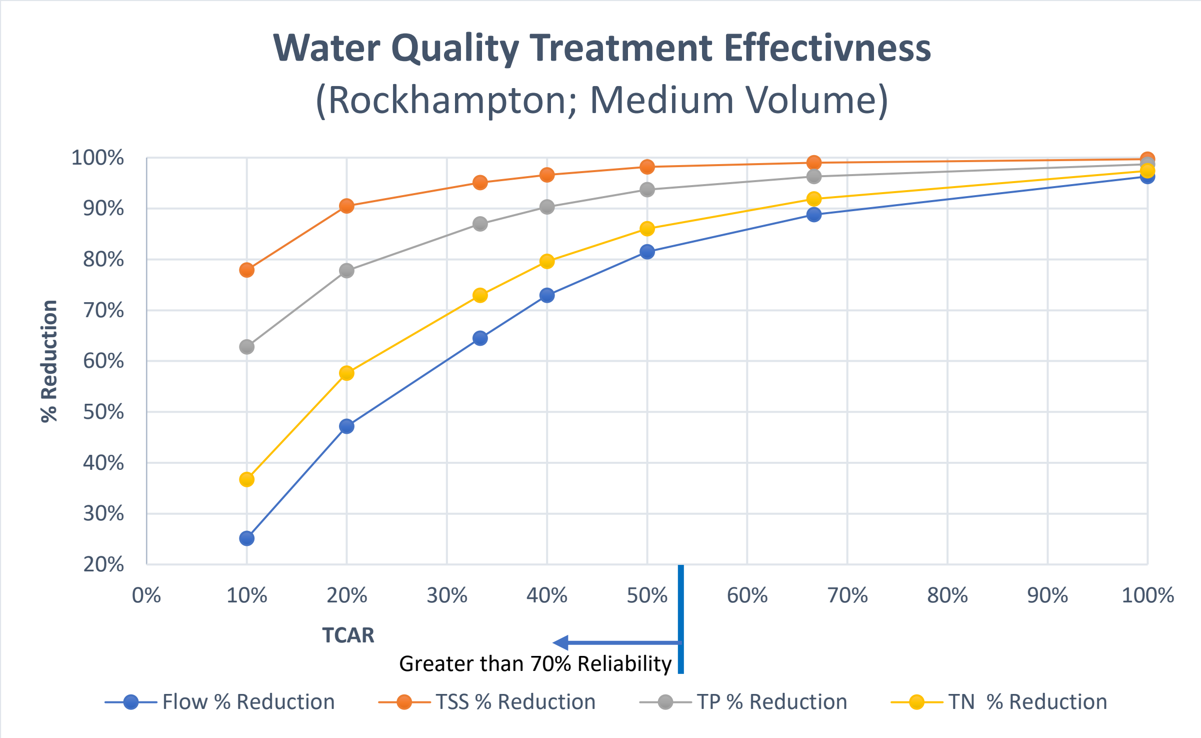
Reliability

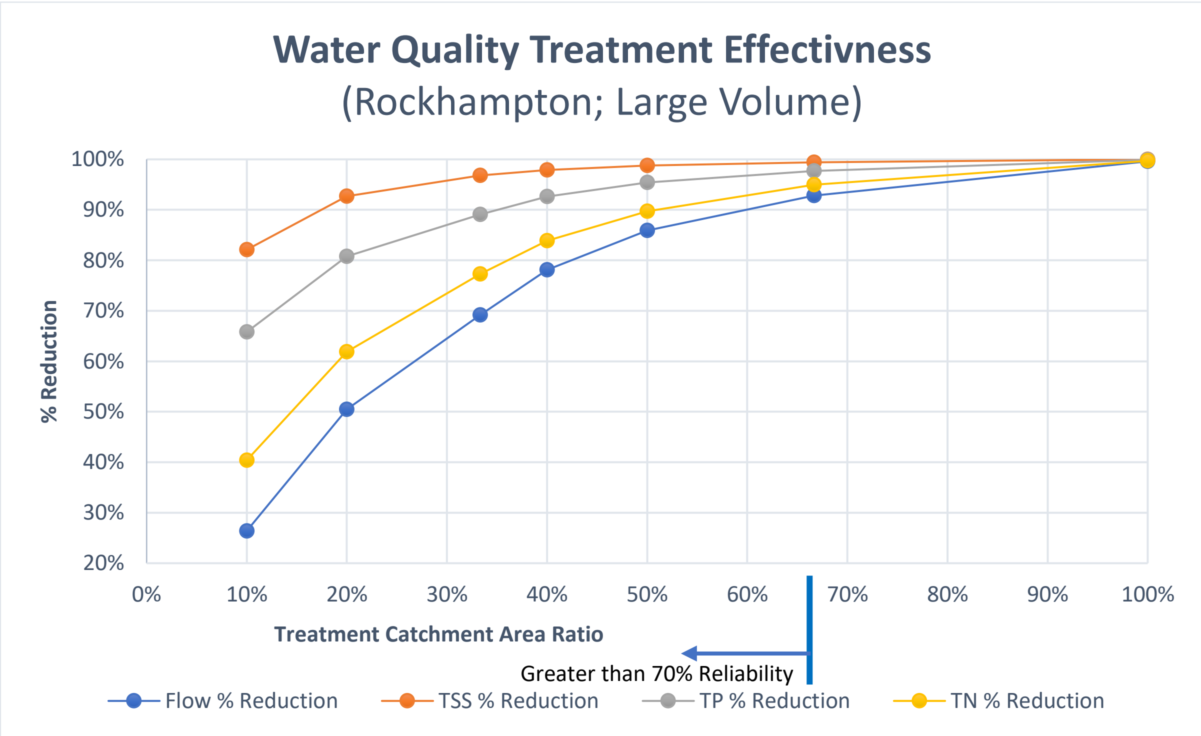


Treatment

(Rockhampton – Water Quality Objectives as per SPP 2017; TSS=85%, TP=70% & TN=45%)

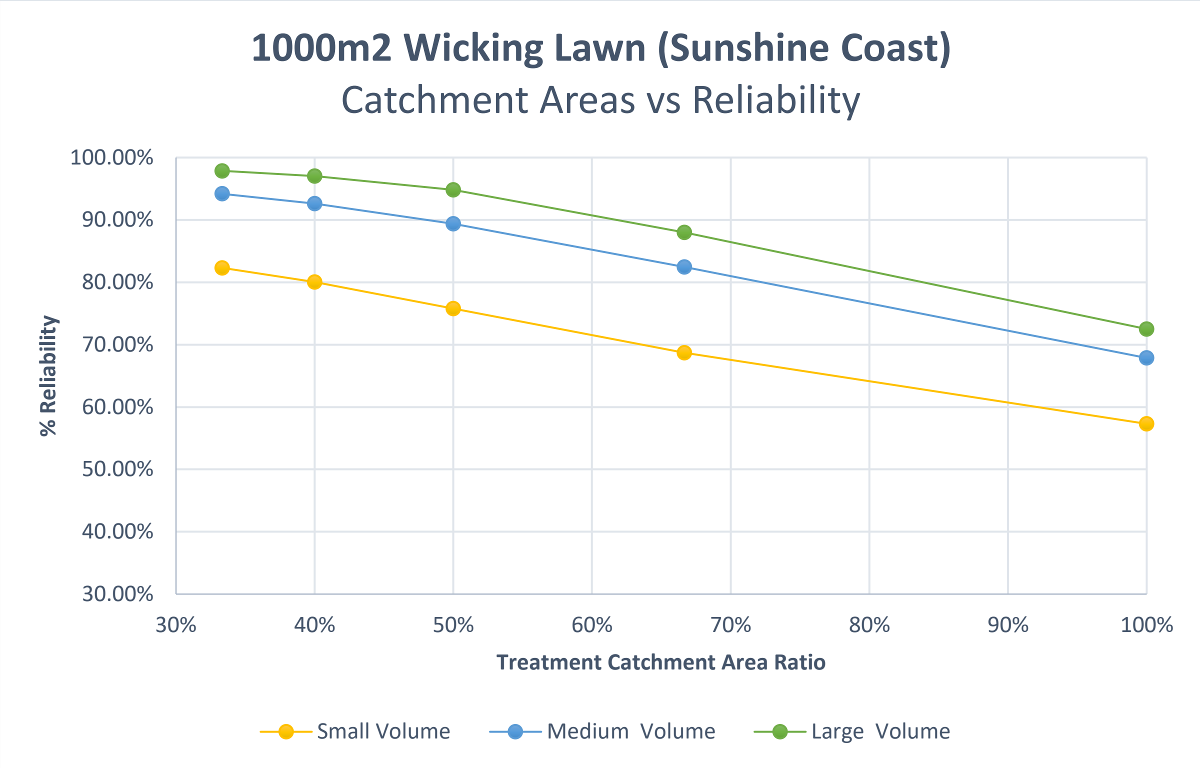



Water Quality Treatment Effectivness
(Rockhampton; Medium Volume)
% Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
TCAR
Greater than 70% Reliability
Flow % Reduction
TSS % Reduction
TP % Reduction
TN % Reduction


Water Quality Treatment Effectivness
(Rockhampton; Large Volume)
% Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Treatment Catchment Area Ratio
Greater than 70% Reliability
Flow % Reduction
TSS % Reduction
TP % Reduction
TN % Reduction

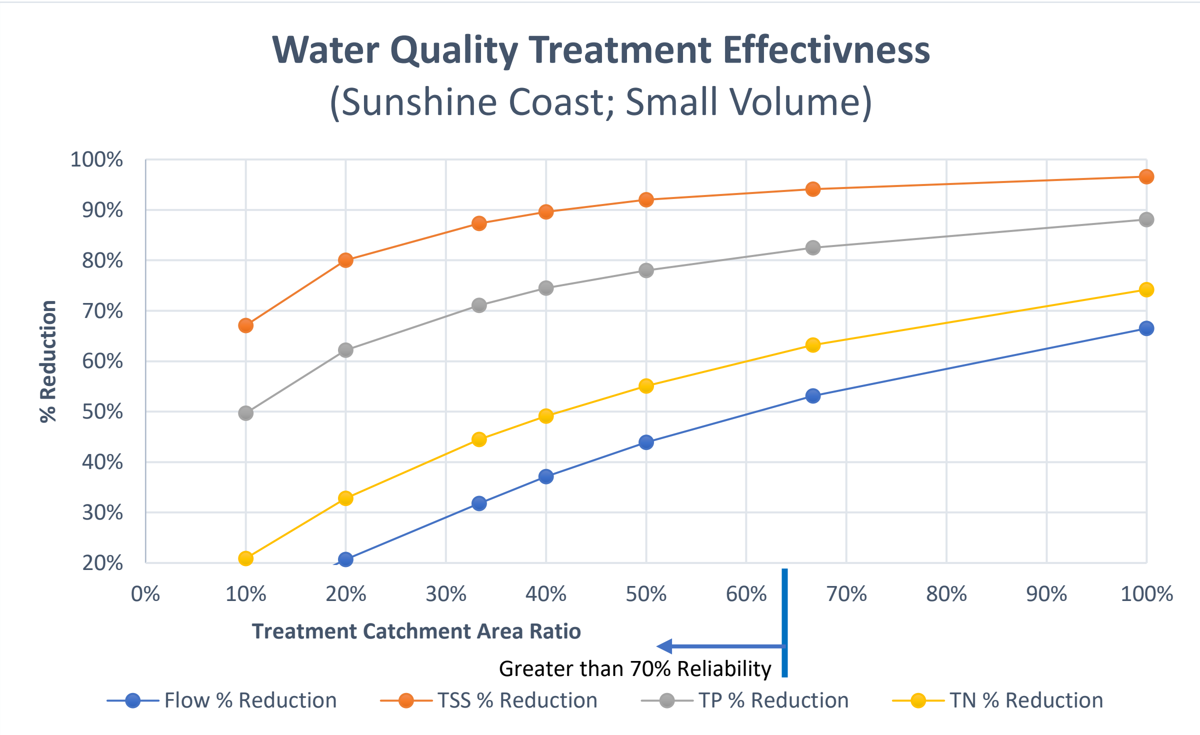
SEQ North Sunshine Coast

Reliability



Treatment

(Sunshine – Water Quality Objectives as per SPP 2017; TSS=80%, TP=60% & TN=45%)



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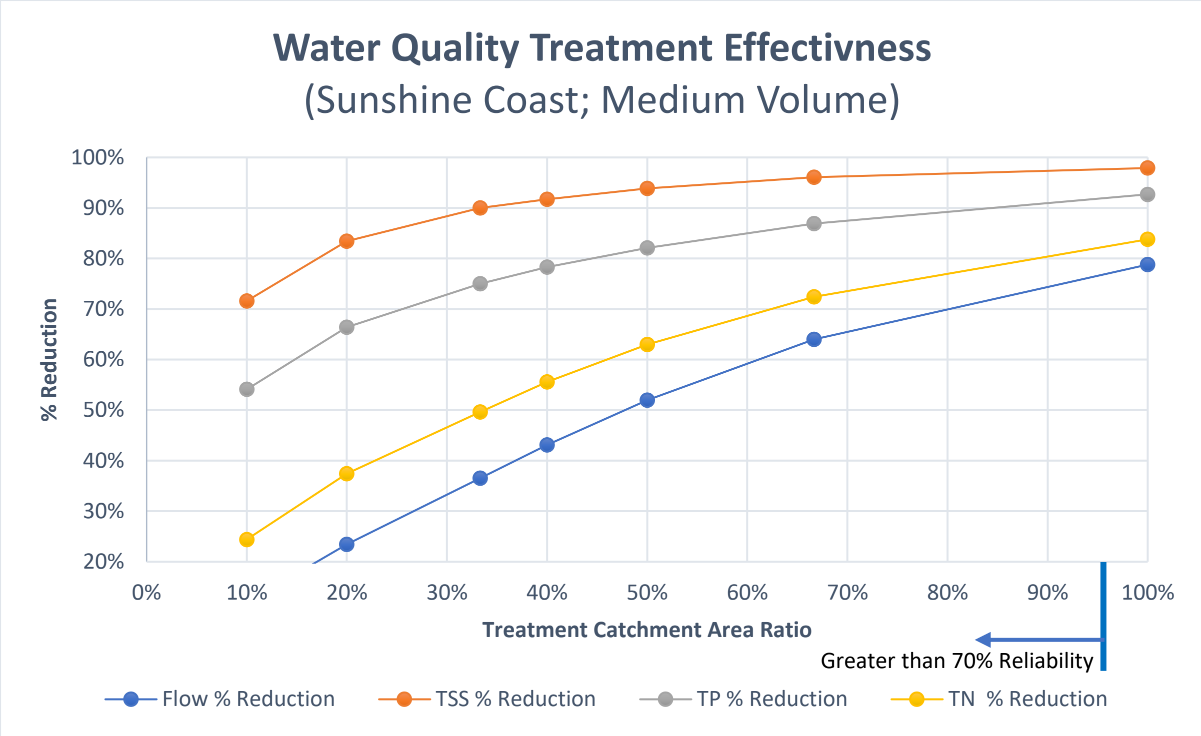
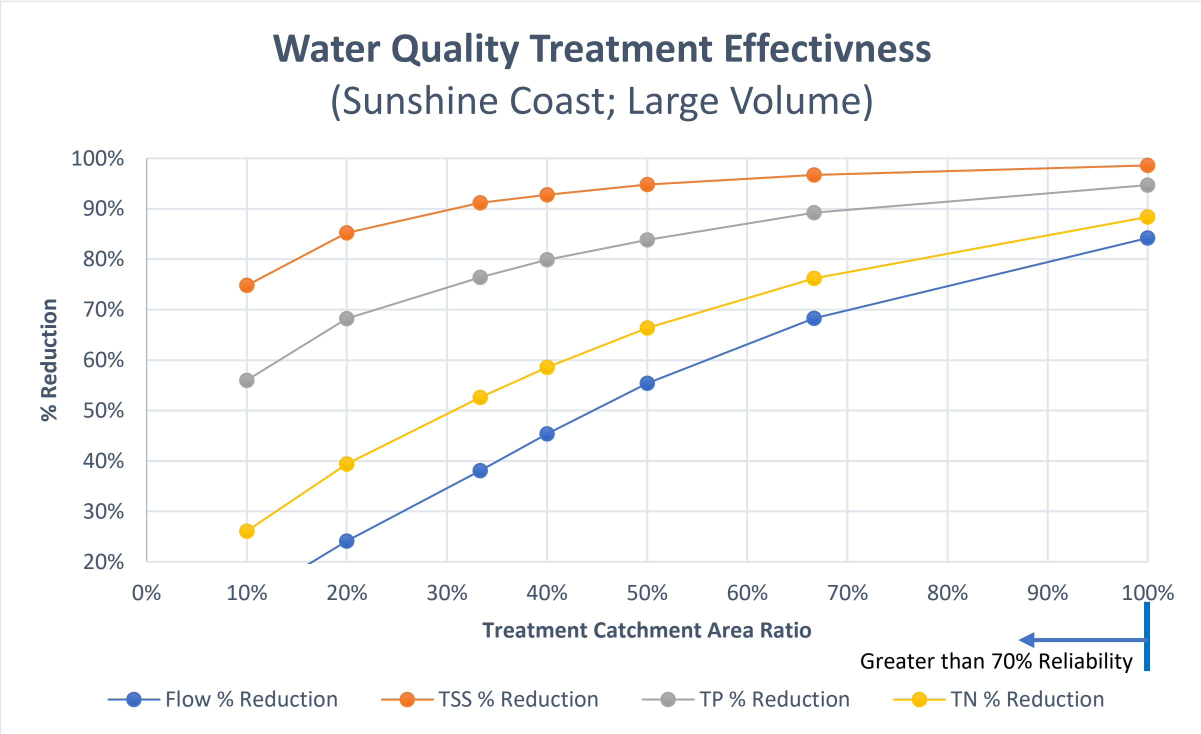
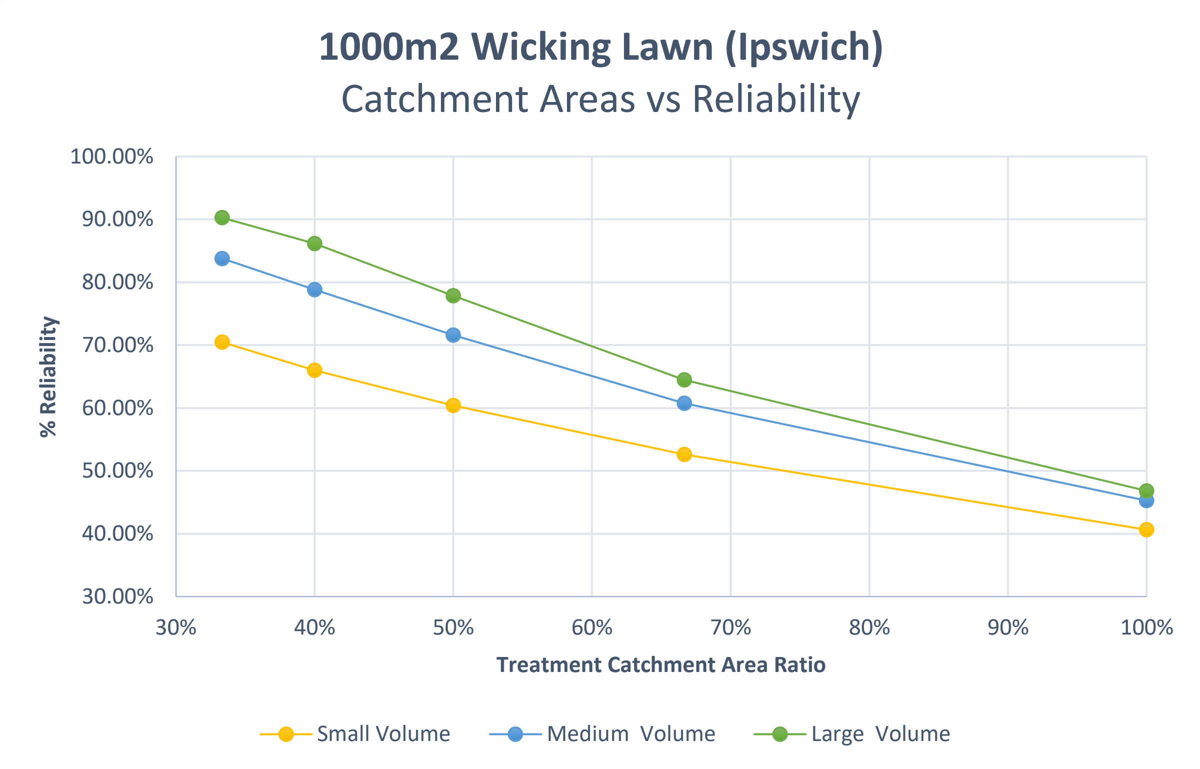

Water Quality Treatment Effectivness
(Sunshine Coast; Medium Volume)
% Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Treatment Catchment Area Ratio
Greater than 70% Reliability
Flow % Reduction
TSS % Reduction
TP % Reduction
TN % Reduction


Water Quality Treatment Effectivness
(Sunshine Coast; Large Volume)
% Reduction
100%
90%
80%
70%
60%
50%
40%
30%
20%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Treatment Catchment Area Ratio
Greater than 70% Reliability
Flow % Reduction
TSS % Reduction
TP % Reduction
TN % Reduction

SEQ West Ipswich

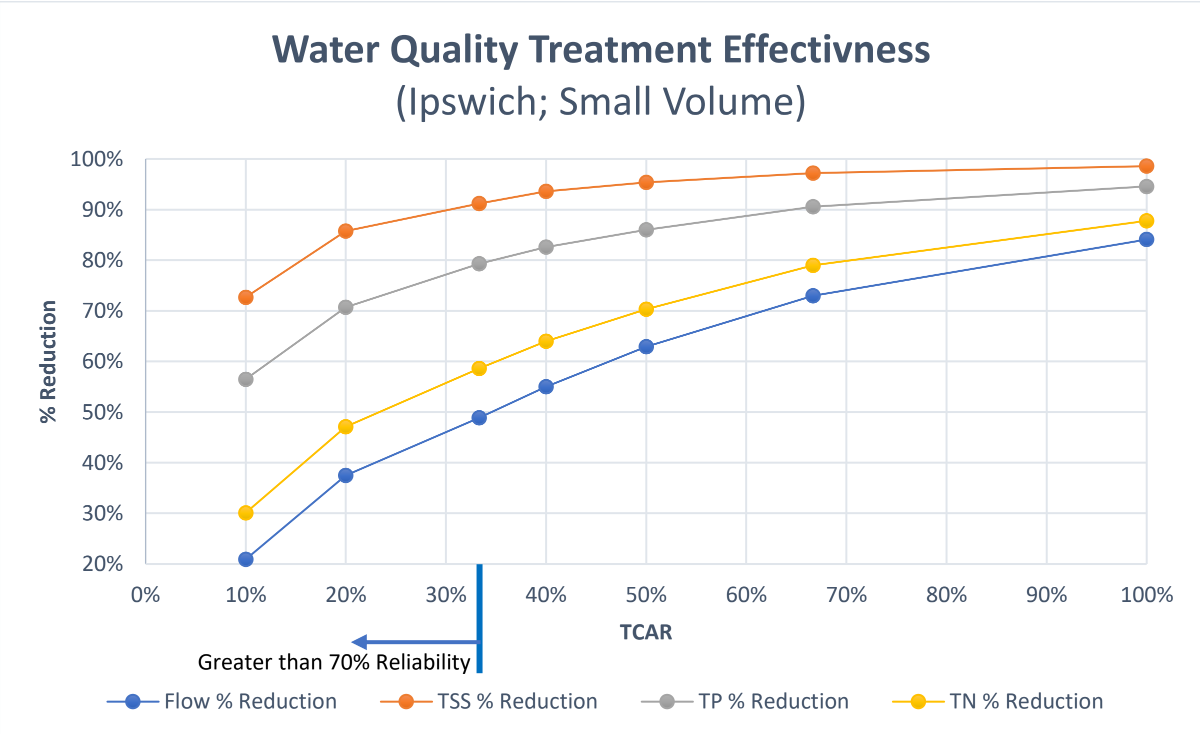
City of Ipswich

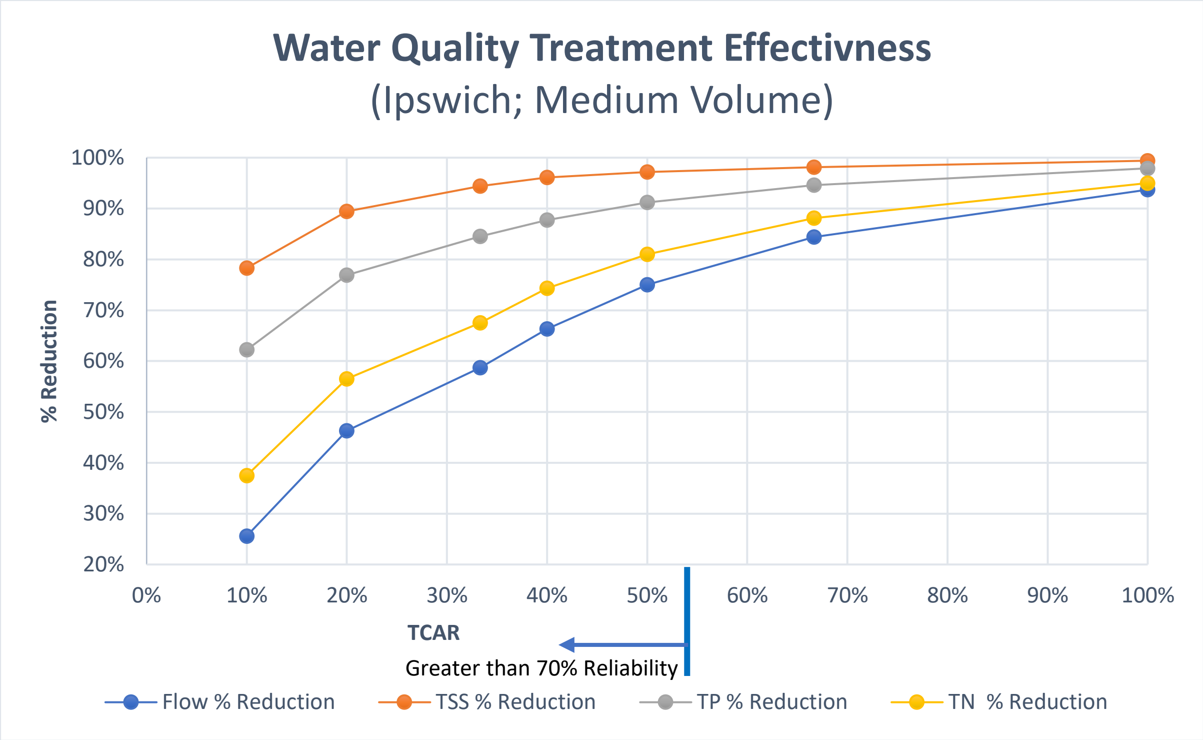
Reliability



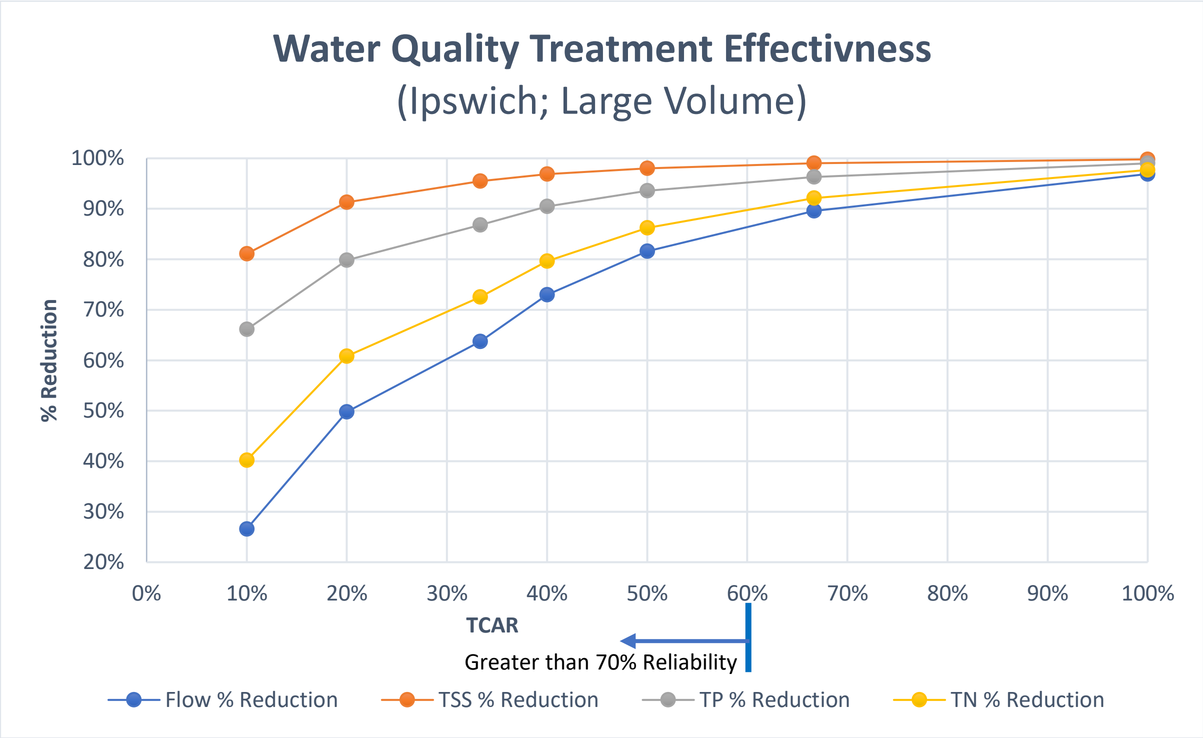
Treatment

(Ipswich – Water Quality Objectives as per SPP 2017; TSS=80%, TP=60% & TN=45%)





Water Quality Treatment Effectivness
(Ipswich; Medium Volume)
100%
90%
80%
70%
60%
50%
40%
30%
20%
% Reduction
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
TCAR
Greater than 70% Reliability
Flow % Reduction
TSS % Reduction
TP % Reduction
TN % Reduction



Water Quality Treatment Effectivness
(Ipswich; Large Volume)
100%
90%
80%
70%
60%
50%
40%
30%
20%
% Reduction
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
TCAR
Greater than 70% Reliability
Flow % Reduction
TSS % Reduction
TP % Reduction
TN % Reduction

Worked Example 02 – Wicking Lawn Kick and Throw Field

Rockhampton Regional Council is seeking to deliver a large kick and throw field as part of their city revitalisation strategy. The vision for the parkland is to provide 'a world-class urban parkland that is accessible for all residents, visitors and workers within Rockhampton'. Delivering on this vision required sustainable water management to help secure water supplies and provide for high amenity green landscapes despite the challenging climatic conditions.

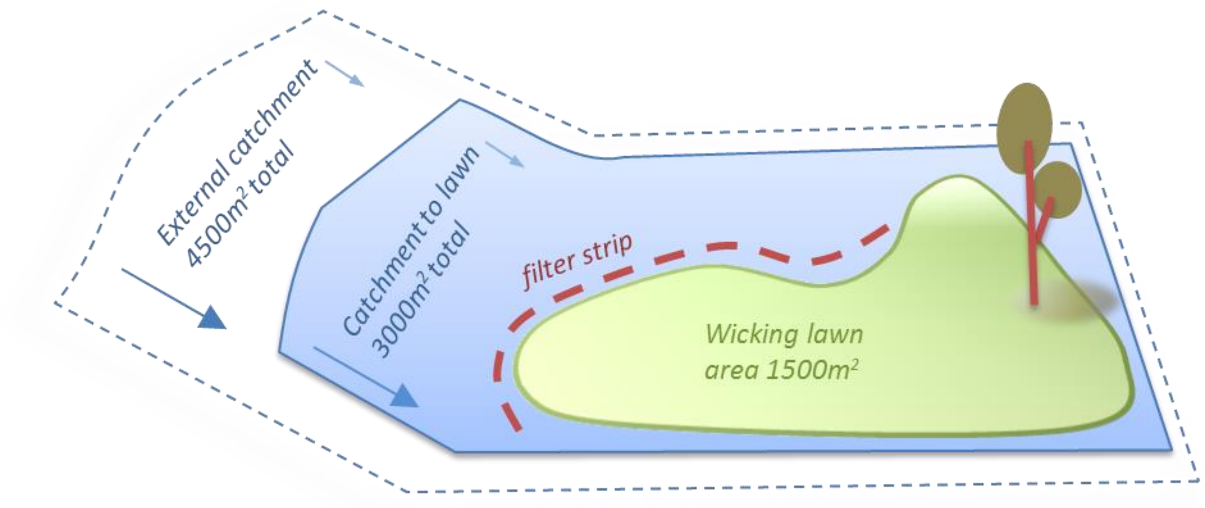


FIGURE 9. WORKED EXAMPLE – WICKING BEDS

The site chosen for the wicking lawn is a turf kick and throw field, 1500m^2 in area (Figure 9). Some of the surrounding catchment falls gently towards the field, hence there is an opportunity to direct runoff from the external catchment to the aquifer storage zone. Pre-treatment of these flow via porous pavement (Figure 10) shall be provided to ensure litter and sediment to not enter the aquifer.

FIGURE 10. PRE-TREATMENT OF SURFACE RUNOFF PRIOR TO DISCHARGE TO WICKING ZONE.

Initially the designer investigated the use of a 150mm deep sand wicking zone, which equates to the 'small volume' modelled. Based on the catchment area vs reliability curve, a catchment of approximately 4500m^2 (TCAR=33%) must be directed to the aquifer to achieve an irrigation reliability of 70%. This area of 4500m^2 includes 1500m^2 of direct rainfall on the turf lawn. Due to the flat grades of the external catchments it was found that an external catchment of only 1500m^2 could be delivered to the base of the wicking layer.

The storage volume of the wicking layer was increased by increasing the depth to 300mm and using a clean fine sand with a porosity of 0.35 and a capillary rise of 400mm (to ensure soil moisture benefit even when water levels in the storage fall to low levels). With the increase in storage volume, irrigation reliability of 70% was achieved with a treatment catchment area ratio of 50% (Figure 11).

For the 3000m^2 catchment treated through direct rainfall and direct recharge of the aquifer, the % reduction is stormwater pollutants are well in excess of the requirements for Rockhampton (Figure 12).

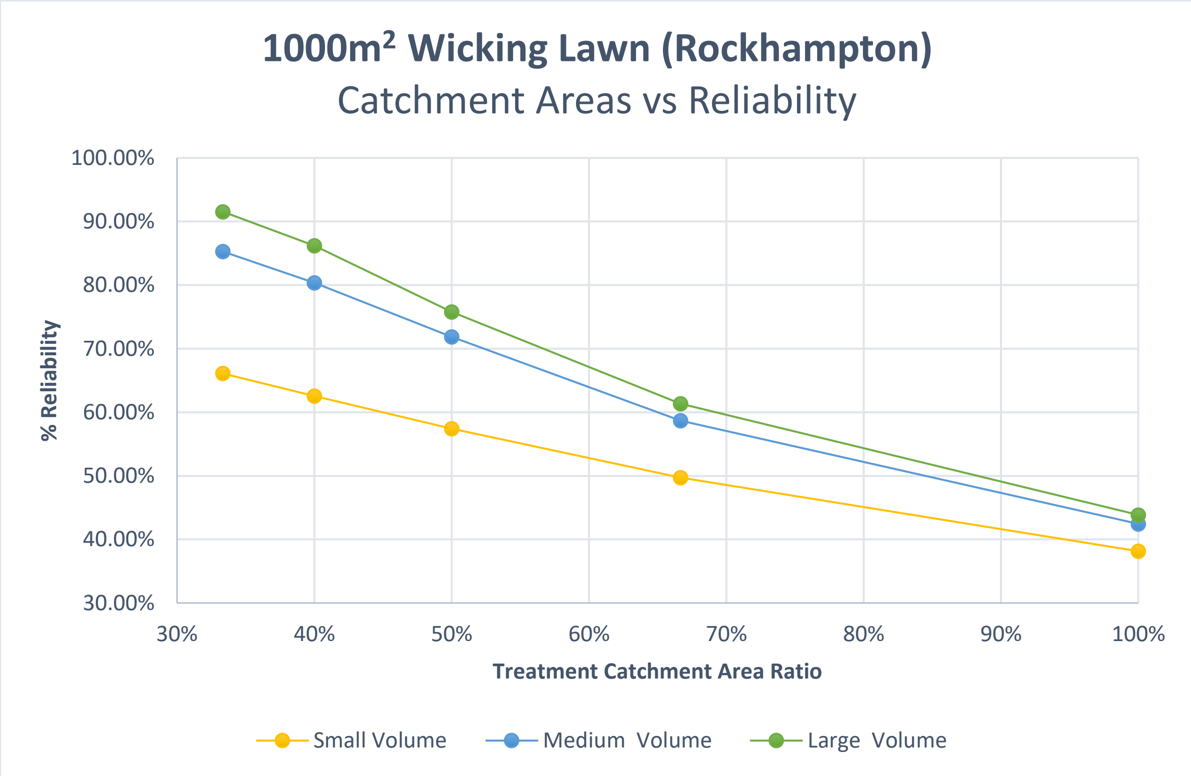


FIGURE 11 WICKING BED RELIABILITY CURVE FOR ROCKHAMPTON.

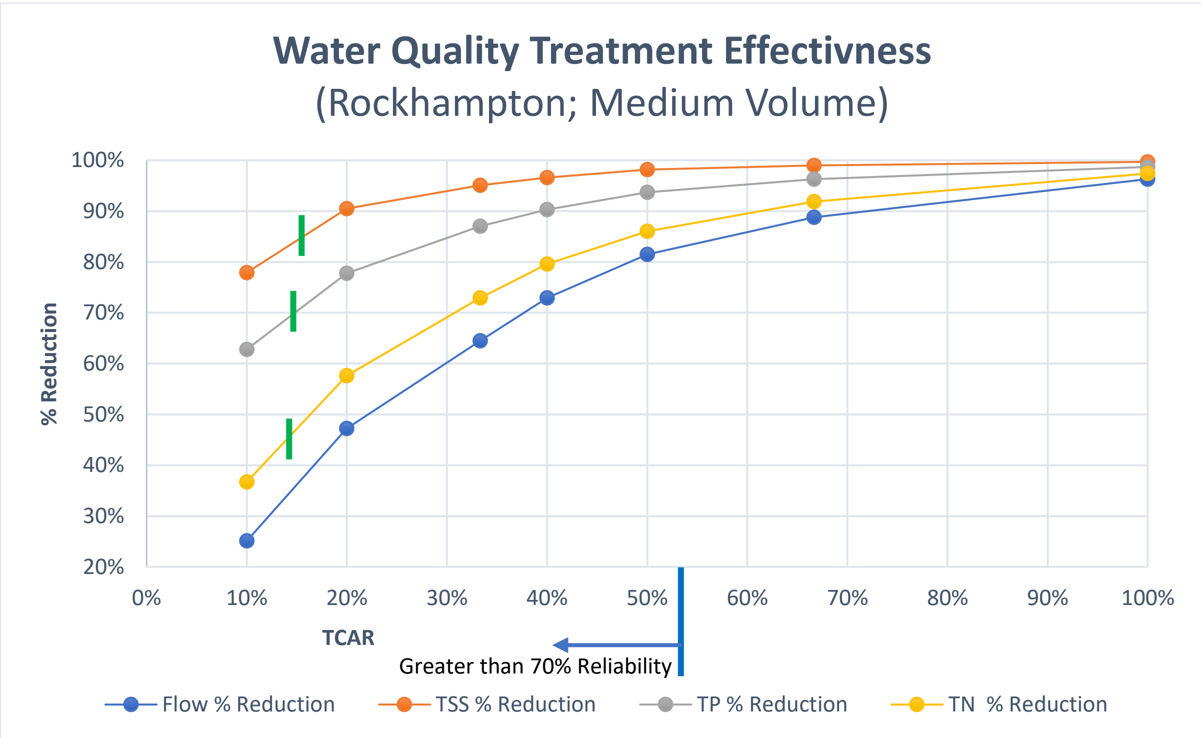


FIGURE 12. TREATMENT EFFECTIVENESS CURVE FOR ROCKHAMPTON. THE GREEN LINES INDICATE THE POINT AT WHICH POLLUTANT LOAD REDUCTION OBJECTIVES ARE MET.

Design and Modelling Parameters

To demonstrate the water quality benefit that passively watered systems can provide, rainfall - runoff models such as the Model for Urban Stormwater Improvement Conceptualisation (MUSIC) can be used. There is no specific treatment node currently provided within MUSIC to represent a passively irrigated tree, thus a bioretention treatment node can be used and the default parameters adjusted to represent the tree pit.

Table 2 provides guidance on the modelling of passively watered trees pits in MUSIC. Refer to local MUSIC modelling guidelines or site data for appropriate catchment parameters (e.g. event mean concentrations, soil properties, catchment imperviousness).

MUSIC modelling parameters have not been defined for turf wicking beds. MUSIC does not currently have the ability to direct rainfall both to the surface and inflows direct to the submerged zone of wicking beds. As such, the work to date has estimated performance based on a bioretention node, which is likely to over-estimate treatment performance and a rainwater tank node, which is likely to underestimate performance. Further work is required to gain certainty around the stormwater treatment performance of wicking beds and how to represent these in MUSIC.

Table 2. MUSIC modelling parameters for passively watered tree pits.

Design Parameter	Design value	Design rationale
BIORETENTION TREATMENT NODE		
Inlet properties		
Low flow bypass	N/A	No low flow bypass.
High flow bypass	Tree pits are designed to treat lows flows (typically 1 EY). Treatable flow rates are determined by the surface area and depth of extended detention.	Tree pits are designed with no overflow pit. Once inflows reach extended detention depth the system will backwater and flows bypass via the kerb and channel to road side entry pit. A large opening/kerb cut out is preferred such that the inlet doesn't restrict inflows. Backwater is the mechanism to engage bypass. If the inlet is constricted, too much flow may bypass and the tree may not get enough water and treatment performance will be reduced.
Bioretention/tree pit properties		
Extended detention	100mm	Tree pit systems are typically suited to 100mm extended detention to reduce level difference with road and pavement surfaces. Greater depths may impact visual amenity and pose public health and safety risks.
Filter area (represents the tree pit surface area)	Generally within the range of 2% to 10% of contributing	Dependent on climatic region, desired tree size, soil volume and soil depth

	stormwater catchment area (refer to Table 1 – Design Guidance)	achievable, catchment land use, imperviousness, extended detention depth and soil type (i.e. filter media saturated hydraulic conductivity).
Filter (top soil) depth	Min 600mm, preferably 800mm to 1000mm.	Shallower depths are at risks of drying out and may not be able to support the tree. Maximum depth may be limited by underdrainage discharge levels.
Filter Media Properties		
Saturated hydraulic conductivity	50mm/hr (Sandy Loam) or 100mm/hr (Loamy Sand)	Media with higher hydraulic conductivities will have lower water holding capacity (WHC) and potentially result in drought-stressed trees. Use of higher hydraulic conductivity soils must demonstrate suitable WHC and horticultural quality.
Nutrient Content	TN < 1000 mg/kg. Available P (Colwell) < 80mg/kg.	Prevents leaching of nutrients from the media.
Organic matter content	Max 5%	Organic matter helps retain water for vegetation and can benefit pollutant removal, however higher levels may lead to nutrient leaching.
Grading of particles	Smooth grading – all particles size classes should be represented across sieve sizes from the 0.05mm to the 3.4mm sieve (as per ASTM F1632-03 (2010).	Provides a stable media, avoiding structural collapse from downward migration of fines.
pH	5.5 – 7.5.	AS 4419-2003 Natural Soils and soil blends.
Electrical conductivity	< 1.2 dS/m.	AS 4419-2003 Natural Soils and soil blends.
Horticultural suitability	Media must be capable of supporting healthy vegetation (assessment by horticulturalist).	To support healthy vegetation over the long term.
Transition Layer Properties		
Material	Clean well-graded sand.	Prevents filter media washing down into the saturated zone. If the saturated zone is composed of sand and bridges with the filter media (i.e. meets the bridging criteria), no additional transitional layer will be required.
Depth	Min 100mm.	To avoid migration of fines from the filter media and to avoid inundation of the filter media by the saturated zone.
Hydraulic conductivity (Ksat)	Higher than Ksat of filter media.	

Fine particle content	< 2%.	Prevents the bioretention system leaching nutrients.
Particle size distribution	D_{15} (transition layer) ≤ 5 x D_{85} (filter media).	Bridging criteria- the smallest 15% of sand particles must bridge with the largest 15% of filter media particles to avoid migration of the filter media downwards into the transition layer.
Saturated (Wicking) Zone Properties		
Material	Clean washed fine – medium sand	The pore space between the sand grains retains the water. A 0.15 to 0.5mm sand will have a porosity of approx. 47% and a capillary rise distance of 400-500mm. Other proprietary wicking zones may have higher porosity but must be able to demonstrate wicking ability.
Saturated zone depth	< capillary rise distance 300mm is recommended	Provides storage of water to maintain soil moisture. 300mm depth of fine-medium sand ensures water can be accessed via capillary rise. Any depth greater than this must be supported by evidence of capillary rise distance which exceeds the depth.
Evapotranspiration (MUSIC PET Scaling Factor)		
High Water Use Landscapes	MUSIC PET Scaling Factor = 1.85	Relates to a crop factor of approx. 1.0
Low Water Use Landscapes	MUSIC PET Scaling Factor = 1.50	Relates to a crop factor of approx. 0.5
Outlet properties		
Overflow pit / weir	Over flow via bypass to roadway side entry pit (preferred) or overflow pit with letter box grate	To take flows in excessive of the extended detention capacity
Underdrainage pipes	Slotted PVC pipe or similar. Capacity of underdrainage pipes are larger than the infiltration capacity of the filter media. Maximum spacing between pipes is 1.5m. Upstand pipes (non-perforated) are connected to the underdrainage and extended to the surface as inspection points under. Pipes must be covered with 150mm of 2-7mm clean aggregate (this is an additional layer if the saturated zone is composed of sand).	Having regular underdrainage pipes ensures the system drains effectively and the water level within the saturated zone does not rise to inundate the filter media. Inspection access allows pipes to be inspected and flushed. The drainage aggregate avoids material falling into the slots of the drainage pipes. Standing water in the filter media /topsoil section of tree pits can result in leaching of nutrients.

We gratefully acknowledge the generous contributions from our project partners:

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E2Designlab:

- Sally Boer
- Dylan Cain
- Peter Breen
- Dale Browne
- Steve Buck

Water by Design:

- Glenn Browning
- Adrian Crocetti
- Andrew O’Neill

DES:

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Reviews:

- Luke Galea
- Ben Walker
- Adam Berry
- Chris Manning
- Jared Johnston

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E2DESIGNLAB

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