Measured Irrigation Manual

A major advance in drip irrigation

Dr Bernie Omodei & Sophie Thomson celebrate the successful installation
of measured irrigation at Sophie's Patch at Mount Barker

Measured irrigation is a radical departure from the current drip irrigation paradigm and the implications for water-efficiency and energy-efficiency are significant.

Measured irrigation is the implementation of two fundamental principles:

1. Variations in the application rate for each dripper throughout the year are controlled by the prevailing weather conditions.
2. Measured irrigation controls the application rate from each dripper by controlling emitted volumes directly without the need to control the flow rate or the duration of the irrigation event.

Dr Bernie Omodei
Measured Irrigation
5/50 Harvey Street East, Woodville Park SA 5011
Phone (08) 8244 0071
Mobile 0403 935277
Facebook Measured Irrigation
Email bomodei@measuredirrigation.com.au
www.measuredirrigation.com.au

February 2017

Contact Bernie Omodei or go to the website for further information or to place an order.

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Chapter 1. Introduction to measured irrigation

1.1 Introduction

Conventional drip irrigation systems use a timer or controller to control the opening and closing of valves in order to control the duration of the irrigation event and the frequency of irrigation. The volume of water delivered to each plant during the irrigation event is controlled by using drippers with a specified flow rate and controlling the duration of the irrigation event. The acceptance of this paradigm has led to the development of pressure compensating drippers whereby the flow rate from the dripper is relatively constant for a range of water pressures. Measured irrigation uses a totally different paradigm for controlling the volume of water delivered to each plant during the irrigation event.

Definition of measured irrigation

Measured irrigation is drip irrigation that satisfies the following two conditions:

1. *The volume of water delivered emitted by each dripper during the irrigation event is controlled directly without the need to control the flow rate or the duration of the irrigation event,*
2. *The application rate for each dripper throughout the year is directly proportional to the net evaporation rate and is independent of the pressure, the flow rate, the irrigation frequency and the duration of the irrigation event.*

Note that the flow rate and the duration of the irrigation event adjust automatically to ensure that the required volume of water is delivered by each dripper. Net evaporation refers to evaporation minus rainfall.

The conventional volume control paradigm requires the control of two variables, namely, flow rate and time. Measured irrigation requires the control of a single variable, namely, volume. Once the focus of attention changes from flow rate and time to volume, then the design of drip irrigation systems may change significantly.

Measured irrigation is a radical departure from the conventional drip irrigation paradigm and the implications for water-efficiency and energy-efficiency are significant. Measured irrigation is a new approach to drip irrigation rather than a new irrigation technology. Existing drip irrigation installations may be upgraded to measured irrigation. However, to maximise water-efficiency and energy-efficiency for an irrigation application, it is preferable that the measured irrigation implementation is designed from scratch.

Convention drip irrigation systems are usually pressurised using pressure compensating drippers designed to operate within the pressure range 100 kPa to 300 kPa. A gravity feed irrigation system that controls the volume of water delivered to each plant is a potential threat to multinational irrigation companies that have billions of dollars invested in pressurised irrigation technology

Gravity feed measured irrigation is well suited to smallholders in poorer countries where access to mains power and mains water is unavailable, unreliable or too expensive. In remote locations where mains power and mains water are unavailable, measured irrigation can provide an automated irrigation system that delivers measured volumes of water to each plant.

Irrigation zones

An irrigation application is often subdivided into zones, whereby the irrigation in any zone is independent of the irrigation in the other zones. For pressurised irrigation the flow rate from the water supply is often insufficient to allow all plants to be irrigated at the same time. Hence for a pressurised irrigation application zones are needed and each zone is irrigated at a different time.

For gravity feed irrigation the flow rate from the drippers is sensitive to changes in ground level. Hence on uneven or sloping ground it is often important to subdivide the gravity feed irrigation application into a number of zones whereby all the drippers in a zone are at approximately the same level.

1.2 Pressurised drip irrigation versus gravity feed measured irrigation

Think twice before you buy a pump for your rainwater tank.
Suppose you walk into your local irrigation supplier and say that you would like to irrigate your garden using a rainwater tank. One of the first issues raised will the choice a suitable pump. Even if you install the system yourself it will still cost you at least $1000.

Gravity feed measured irrigation is much simpler than pressurised drip irrigation and if it is unpowered the total cost of the irrigation system will be less than the cost of the pump alone.

The downside of pressurised drip irrigation is the cost and maintenance. The system is quite complicated with many things that can you wrong. The system need to be checked frequently for blocked drippers and for leaks. Pressurised drip irrigation is more expensive than any other watering system.

Because gravity feed measured irrigation is incredibly simple, there are fewer things to go wrong. You don't need an irrigation controller, solenoid valves or hose clamps, and so you will save a lot of time installing the system.

To save water and protect your plants, it is very important to adjust the watering to take account of the prevailing weather conditions. For example, when it is hot and dry you will need a lot more water. And when it rains you don't need to water the garden at all.

Pressurised drip irrigation does not automatically respond to the prevailing weather conditions. For example, an irrigation controller cannot respond to an unexpected heat wave. Measured irrigation does automatically respond to the prevailing weather conditions, and so you don't need an irrigation controller. For example, measured irrigation will automatically stop watering in Adelaide during the months of June, July and August - in these months the rainfall is greater than the evaporation.

The table below summarises the differences between pressurised drip irrigation and gravity feed measured irrigation.

Pressurised drip irrigation	Gravity feed measured irrigation
Requires access to mains water or to mains power (to operate a high pressure pump).	Does not require access to mains water or to mains power, and hence can be installed in remote locations.
Pressure compensating (regulated) drippers are required to control of the volume of water delivered by each dripper.	The volume of water delivered to each zone and the volume of water delivered by each dripper within each zone are controlled directly and the volumes are independent of the flow rate.
The application rate does not respond automatically to the prevailing weather conditions.	The application rate responds automatically to the prevailing weather conditions and is directly proportional to the current net evaporation rate.
The irrigation is controlled by an irrigation controller or timer.	The irrigation is controlled by evaporation from and rainfall into a container.
Hose clamps are necessary.	Hose clamps are not needed due to very low pressure.
A water tank needs a high pressure pump (for example, 500 watts).	A water tank may need a low pressure pump (for example, 14 watts).
Uses sophisticated technology.	Uses simple technology (fewer things to go wrong).

1.3 Emitters and nozzles for gravity feed measured irrigation

For gravity feed measured irrigation, all the emitters in a zone should have the same emitter discharge exponent (see Appendix 1). Hence, a combination of different emitters can be used in a zone provided that they all have the same emitter discharge exponent. Drippers for gravity feed measured irrigation may be unregulated online drippers or unregulated inline drippers (pressure compensating drippers should only be used for pressurised measured irrigation). Emitters for gravity feed measured irrigation may be made from short blunt stainless steel needles with different internal diameters. Emitters for gravity feed measured irrigation may also be short lengths of microtube or gravity feed porous hose.

In the context on gravity feed measured irrigation, the word **nozzle** is used to refer to a short cylindrical tube for restricting the flow.

1.4 Nozzles available from the measured irrigation website

Table 1 provides a list of nozzles recommended for gravity feed measured irrigation and available from the measured irrigation website. All of the nozzles have an emitter discharge coefficient of 0.5. The table also provides the flow rate in L/h at a pressure of 100 kPa.

Table 1 Recommended nozzles for gravity feed measured irrigation

nozzle number	nozzle name	description	flow rate in L/h at 100 kPa
N1	Miniscape dripper	Netafim Miniscape (Landline 8) dripper in brown drip tube 6 mm ID	2.00
N2	green	stainless steel needle nozzle 0.56 mm ID and 2 white dots	4.15
N3	yellow	stainless steel needle nozzle 0.64 mm ID and 3 white dots	6.27
N4	Bioline dripper	Netafim Bioline dripper in purple drip tube 13mm ID	8.00
N5	brown	stainless steel needle nozzle 0.79 mm ID and 5 white dots	10.6
N6	pink	stainless steel needle nozzle 0.99 mm ID and 6 white dots	18.0
N7	white	stainless steel needle nozzle 1.17 mm ID and 7 white dots	28.6
N8	purple	stainless steel needle nozzle 1.35 mm ID and 8 white dots	36.0
N9	orange	stainless steel needle nozzle 1.51 mm ID and 9 white dots	50.3
N10	olive	stainless steel needle nozzle 1.77 mm ID and 10 white dots	65.0
N11	small rivet	stainless steel small rivet nozzle	130
N12	medium rivet	stainless steel medium rivet nozzle	197
N12	large rivet	stainless steel large rivet nozzle	263
N13	5/32 inch washer	stainless steel washer nozzle 5/32 inch ID	484
N14	5 mm washer	stainless steel washer nozzle 5 mm ID	873
N15	1/4 inch washer	stainless steel washer nozzle 1/4 inch ID	1371
N16	7 mm	black plastic nozzle 7 mm ID	1943
N18	2 mm valve	black plastic valve nozzle 2 mm ID	230
N19	9 mm valve	black plastic valve nozzle 9 mm ID	2655
N20	white tapered	white tapered plastic nozzle (cut off tip for desired flow rate)	

Nozzles available from the measured irrigation website (flow-splitter nozzles illustrated). The needle nozzles are illustrated both with and without the protective black tube.

gravity feed porous hose

Gravity feed porous hose is made from a combination of recycled rubber and plastic so that the porosity is suitable for gravity feed irrigation. A major disadvantage of porous hose compared with emitter nozzles is the low level of uniformity along the length of the hose. The lack of uniformity is a consequence of the manufacturing process. Another disadvantage of porous hose is that the porosity decreases as the temperature increases. Porous hose should not be used with water that has a high salt content, for example, bore water.

Head loss is rarely a problem provided that the gravity feed porous hose is less than 5 metres long. If a part of the hose is more than 5 metres away from its water supply from the polypipe, you may wish to measure the head loss along the length of the hose by inserting a pressure monitor tube (see Section 4.1) at each end of the porous hose. For long lengths of porous hose, it may be possible to compensate for head loss by adjusting the level of the hose so that there are identical pressures in the pressure monitor tubes at each end.

Gravity feed porous hose should not be used in pressurised systems, and conventional porous hose for pressurised systems should not be used with gravity feed measured irrigation. Conventional porous hose is much less porous than gravity feed porous hose and hardly any water will weep from the hose at low pressure.

Gravity feed porous hose is available from the measured irrigation website. A specialized porous hose for gravity feed irrigation is manufactured in USA for a company called *Rain Barrel Soaker Hose.* Details are available from their website http://www.rainbarrelsoakerhose.com

For above surface irrigation, emitter nozzles or drippers are preferable to gravity feed porous hose. However, gravity feed porous hose may be suitable for subsurface irrigation. Root invasion is not a problem with subsurface gravity feed porous hose. See 14.5 for an example of subsurface watering of pot plants.


Gravity feed porous hose

1.5 Nozzle ratios

For any two nozzles with the same emitter discharge exponent and at the same pressure, the ratio of the volumes of water emitted by the two nozzles is a constant called the **nozzle ratio**. The nozzle ratio is independent of the pressure.

For any measured irrigation application there is a special nozzle called the **control nozzle** that drips water into a container (called the evaporator). By controlling the volume of water that drips into the container during the irrigation event, the first condition in the definition of measured irrigation is satisfied:

> *The volume of water delivered emitted by each dripper during the irrigation event is controlled directly without the need to control the flow rate or the duration of the irrigation event.*

The nozzle ratios for the nozzles in Table 1 are listed below in Table 2.

Table 2 Nozzle ratios emitter nozzle to control nozzle

control nozzle

emitter nozzle (or flow-splitter nozzle)

	Miniscape dripper	green	yellow	Bioline dripper	brown	pink	white	purple	orange	olive	small rivet	medium rivet	large rivet	5/32 washer	5 mm washer	1/4 washer	7mm
nozzle 1 Miniscape dripper	1.00	0.529	0.351	0.250	0.207	0.122	0.0769	0.0611	0.0436	0.0338	0.0169	0.0111	0.0084	0.0045	0.0025	0.0016	0.0011
nozzle 2 green	2.08	1.00	0.663	0.519	0.392	0.231	0.145	0.1155	0.0825	0.0639	0.0319	0.0210	0.0158	0.0086	0.0048	0.0030	0.0021
nozzle 3 yellow	3.13	1.51	1.00	0.783	0.591	0.348	0.219	0.174	0.124	0.0964	0.0481	0.0317	0.0238	0.0129	0.0072	0.0046	0.0032
nozzle 4 Bioline dripper	4.00	1.93	1.28	1.00	0.755	0.444	0.280	0.222	0.159	0.123	0.0615	0.0405	0.0304	0.0165	0.0092	0.0058	0.0041
nozzle 5 brown	5.30	2.55	1.69	1.32	1.00	0.589	0.371	0.295	0.210	0.163	0.0814	0.0536	0.0403	0.0219	0.0121	0.0077	0.0055
nozzle 6 pink	9.00	4.33	2.87	2.25	1.70	1.00	0.630	0.500	0.358	0.277	0.138	0.091	0.0684	0.0372	0.0206	0.0131	0.0093
nozzle 7 white	14.3	6.88	4.56	3.57	2.70	1.59	1.00	0.794	0.568	0.439	0.219	0.145	0.109	0.0590	0.0327	0.0208	0.0147
nozzle 8 purple	18.0	8.7	5.74	4.50	3.40	2.00	1.26	1.00	0.715	0.553	0.276	0.182	0.137	0.0743	0.0412	0.0262	0.0185
nozzle 9 orange	25.2	12.1	8.03	6.29	4.75	2.80	1.76	1.40	1.00	0.774	0.387	0.255	0.191	0.104	0.0577	0.0367	0.0259
nozzle 10 olive	32.5	15.7	10.4	8.13	6.14	3.61	2.28	1.81	1.29	1.00	0.500	0.329	0.247	0.134	0.0745	0.0474	0.0335
nozzle 11 small rivet	65.1	31.3	20.8	16.3	12.3	7.23	4.56	3.62	2.59	2.00	1.00	0.659	0.495	0.269	0.149	0.0949	0.0670
nozzle 12 medium rivet	98.7	47.5	31.5	24.7	18.6	11.0	6.91	5.49	3.92	3.04	1.52	1.00	0.751	0.408	0.226	0.144	0.102
nozzle 13 large rivet	131	63.3	42.0	32.9	24.8	14.6	9.20	7.31	5.22	4.04	2.02	1.33	1.00	0.543	0.301	0.192	0.135
nozzle 14 5/32 washer	242	117	77.2	60.5	45.7	26.9	16.9	13.5	9.61	7.44	3.72	2.45	1.84	1.00	0.554	0.353	0.249
nozzle 15 5 mm washer	437	210	139	109	82.4	48.5	30.6	24.3	17.3	13.4	6.71	4.42	3.32	1.80	1.00	0.637	0.449
nozzle 16 1/4 washer	686	330	219	171	129	76.2	48.0	38.1	27.2	21.1	10.5	6.94	5.22	2.83	1.57	1.00	0.71
nozzle 17 7mm	971	468	310	243	183	107.9	68.0	54.0	38.6	29.9	14.9	9.84	7.39	4.01	2.23	1.42	1.00

1.6 Implementations of measured irrigation

In the following Chapters (2, 3, 4, 5, 6, 7, 8 and 9) eight implementations of measured irrigation will be introduced and discussed in detail. The table below provides a summary of the key differences between the implementations. The table may assist you to choose the appropriate implementation for your particular application.

	Pressurised drip irrigation unpowered upgrade	**Pressurised drip irrigation solar-powered upgrade**	**Unpowered single-zone gravity feed**	**Unpowered multi-zone gravity feed**	**Solar-powered single-zone gravity feed with emitters at the same level**	**Solar-powered single-zone gravity feed with emitters at different levels**	**Solar-powered multi-zone gravity feed with flow-splitter**	**Solar-powered multi-zone gravity feed without flow-splitter**
	Chapter 2	**Chapter 3**	**Chapter 4**	**Chapter 5**	**Chapter 6**	**Chapter 7**	**Chapter 8**	**Chapter 9**
Gravity feed	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Completely automatic	No	Yes	No	No	Yes	Yes	Yes	Yes
Multi-zone	Yes	Yes	No	Yes	No	No	Yes	Yes
Emitters at different levels	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Multiple evaporators and control nozzles	Yes	Yes	No	Yes	No	No	No	Yes
Header tank with float valve or float switch	No	No	No	No	No	Yes	No	No
Installation cost	Zero	Low	Low	Low	Medium	Medium	High	Medium

Table 5 Key differences between the eight implementations of measured irrigation

Chapter 2. Pressurised drip irrigation upgrade to unpowered pressurised measured irrigation

2.1 Introduction to pressurised drip irrigation upgrade to unpowered pressurised measured irrigation

This is a zero cost innovation. All that you need is a bucket per zone.

It is recommended that you watch the YouTube video entitled *Irrigation innovation uses the weather to control litres per week per dripper* https://www.youtube.com/watch?v=7qK1Rwzlsko

Before you upgrade to pressurised measured irrigation, you should check that identical drippers in your garden have the same flow rate. This is unlikely to be a problem if you are using regulated (pressure compensating) drippers.

For each zone, a container with vertical sides is placed at a location in the zone so that one of the drippers drips water into the container during the irrigation event. A level line is marked on the inside of the container about 3 cm below the overflow level.

Start watering when the water level is below the level line and the garden needs watering. Stop watering when the water level reaches the level line. Due to evaporation the water level will fall and so the cycle continues indefinitely. The container is called the evaporator. When it is very hot, water evaporates more quickly and your garden will get more water per week. And when it rains the water level rises above the level line and you will start the next watering much later.

A pressure compensating dripper drips water into a bucket.

By using a container in this way, you can save a lot of water because the number of litres per week emitted by each dripper is controlled by the weather.

The number of litres per week emitted by each dripper is directly proportional to the net evaporation rate.

A bucket and the weather are used to control the irrigation. It is important to realise that an irrigation controller or a timer cannot adjust to changes in the weather. For example, if there is an unexpected heat wave, an irrigation controller will continue to follow its program and ignore the heat wave. If you happen to be on holidays at the time your plants may die.

2.2 How to upgrade pressurised drip irrigation to unpowered pressurised measured irrigation

Step 1 For each zone, select a suitable evaporator with vertical sides. If all the drippers in the zone are the same, then the volume of water emitted by each dripper during the irrigation event is the same as the net volume of water that has evaporated from the evaporator since the previous irrigation.

Step 2 Mark a level line on the inside of the evaporator about 3 cm below the overflow level.

Step 3 Install the evaporator in a suitable location so that a single dripper (called the control dripper) drips water into the evaporator during the irrigation event.

Step 4 Fill the evaporator with water until the water level is just below the level line and commence irrigating.

Step 5 Stop irrigating when the water level reaches the level line.

Step 6 The water level in the evaporator falls due to evaporation. Start irrigating again when the water level is below the level line and the next irrigation is required. The cycle continues indefinitely.

Nozzle ratio (see Section 1.5)

For any irrigation dripper in a zone, the nozzle ratio is the ratio of the flow rate of the irrigation dripper to the flow rate of the control dripper.

If an irrigation dripper in a zone is not the same as the control dripper, then the volume of water emitted by the irrigation dripper during the irrigation event is equal to the net volume of water that has evaporated from the evaporator since the previous irrigation multiplied by the nozzle ratio.

Suppose that the control dripper for a zone is a pressure compensating dripper with a flow rate of 2 L/h. Then the volume of water emitted by the control dripper during the irrigation event is the net volume of water that has evaporated from the evaporator since the previous irrigation.

Doubling the application rate

The application rate for a zone can be doubled by replacing each 2 L/h irrigation dripper by a 4 L/h irrigation dripper.

Halving the application rate

The application rate for a zone can be halved by halving the surface area of evaporation of the evaporator for the zone. The surface area of evaporation can be reduced by using one or more plastic containers filled with water and sealed. The plastic containers are positioned so that they sit on the bottom of the evaporator. Plastic drink bottles are ideal for reducing the surface area of evaporation.

An alternative way to halve the application rate for a zone is to replace the 2 L/h control dripper by a 4 L/h dripper (or two 2 L/h drippers).

2.3 Measured Irrigation Nozzle Selector Tool for pressurised drip irrigation upgrade

The Measured Irrigation Nozzle Selector Tool is a powerful interactive spreadsheet used to select the appropriate nozzles for a broad range of measured irrigation applications. If you decide to use the Measured Irrigation Nozzle Selector Tool, it is preferable that the evaporator be exposed to full sun. For a pressurised drip irrigation upgrade one should use the *pressurised irrigation upgrade* worksheet shown at the end of this section.

Using the nozzle selector tool for pressurised drip irrigation upgrade with BOM data

1. Measure the surface area of evaporation for your evaporator and adjust the relevant cell in the *pressurised irrigation upgrade* worksheet.
2. Using the BOM (Bureau of Meteorology) evaporation data worksheet, find the BOM weather station nearest to your property (the weather stations are in alphabetical order). Copy and paste the mean monthly evaporation data January to December into the *pressurised irrigation upgrade* worksheet.
3. Go to the BOM website www.bom.gov.au/climate/data/index.shtml . Enter the location of your property and follow the prompts to find the weather station nearest to your property and then click *Get Data.* At the bottom of the data you there is the heading *Summary statistics for all years.* Copy and paste the mean monthly rainfall data January to December into the *pressurised irrigation upgrade* worksheet.
4. The *pressurised irrigation upgrade* worksheet provides an estimate of the application rate in litres per week for each dripper for each month of the year.

Pressurised irrigation upgrade worksheet

Pressurised drip irrigation upgrade to pressurised measured irrigation

Dripper application rates in this worksheet are based on monthly evaporation and rainfall data.

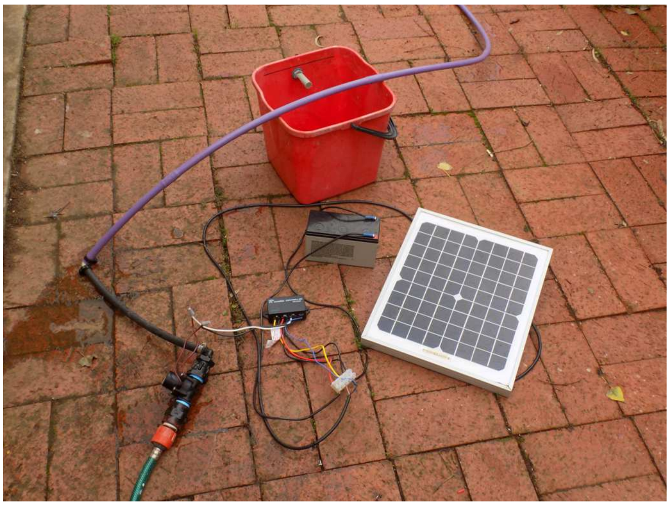
enter surface area of evaporation in m^2	0.109													
	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec		
copy and paste the average monthly evaporation in mm (in Australia use the BOM evaporation data worksheet)	284.7	239.8	203.2	130.9	82.4	57.7	61.1	85.2	120.6	175.0	220.3	257.1	Adelaide Airport	
copy and paste the average monthly rainfall in mm	17.5	19.2	22.1	35	54.1	56.9	59.7	50.5	45.1	36.6	24.8	23.4	Adelaide Airport	
nett evaporation in mm	267.2	220.6	181.1	95.9	28.3	0.8	1.4	34.7	75.5	138.4	195.5	233.7		
In Australia, monthly rainfall data is available from the Bureau of Meteorology website:						http://www.bom.gov.au/climate/data/index.shtml								
	L/week Jan	L/week Feb	L/week March	L/week April	L/week May	L/week June	L/week July	L/week Aug	L/week Sept	L/week Oct	L/week Nov	L/week Dec	L/year	average L/week
Dripper application rate in litres per week	6.58	6.01	4.46	2.44	0.70	0.02	0.03	0.85	1.92	3.41	4.81	5.75	161	3.09

Chapter 3. Pressurised drip irrigation upgrade to solar-powered automated pressurised measured irrigation

3.1 Single-zone pressurised drip irrigation upgrade to solar-powered automated pressurised measured irrigation

The first step is to upgrade pressurised drip irrigation to unpowered pressurised measured irrigation following the steps in Section 2.2. The following components are needed to fully automate the irrigation using power from a solar panel.

- monocrystalline solar panel 12V 10W
- sealed lead acid battery 12V 7.2Ah
- charge controller with night only option
- solenoid valve 12V DC
- float switch
- power relay



Solar panel, battery, charge controller, solenoid valve and float switch

Float switch mounted on the side of bucket

Install the solar panel and the solenoid valve and then follow Steps 8 and 9 in Section 6.8.

The irrigation will start after sunset provided that the float switch is on. The irrigation will stop when the water level has risen and turned off the float switch (or when the sun rises).

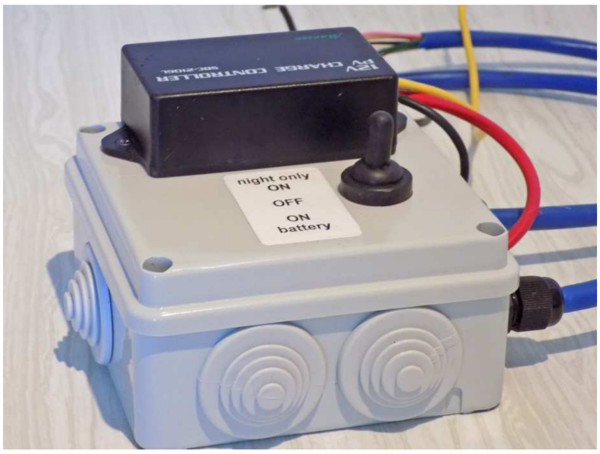
The charge controller, solenoid valve, float switch and power relay may be purchased from the measured irrigation website.

3.2 4-zone pressurised drip irrigation upgrade to solar-powered automated pressurised measured irrigation

For this implementation of measured irrigation you will need to purchase a **4-zone MI controller** from the measured irrigation website.

It is recommended that you watch the YouTube video entitled *Measured Irrigation Controller* https://www.youtube.com/watch?v=R3JZp955ClA&list=PLGypMhdPY6DPFpTGnVy_gLrwq_OOpiy0g&index=2

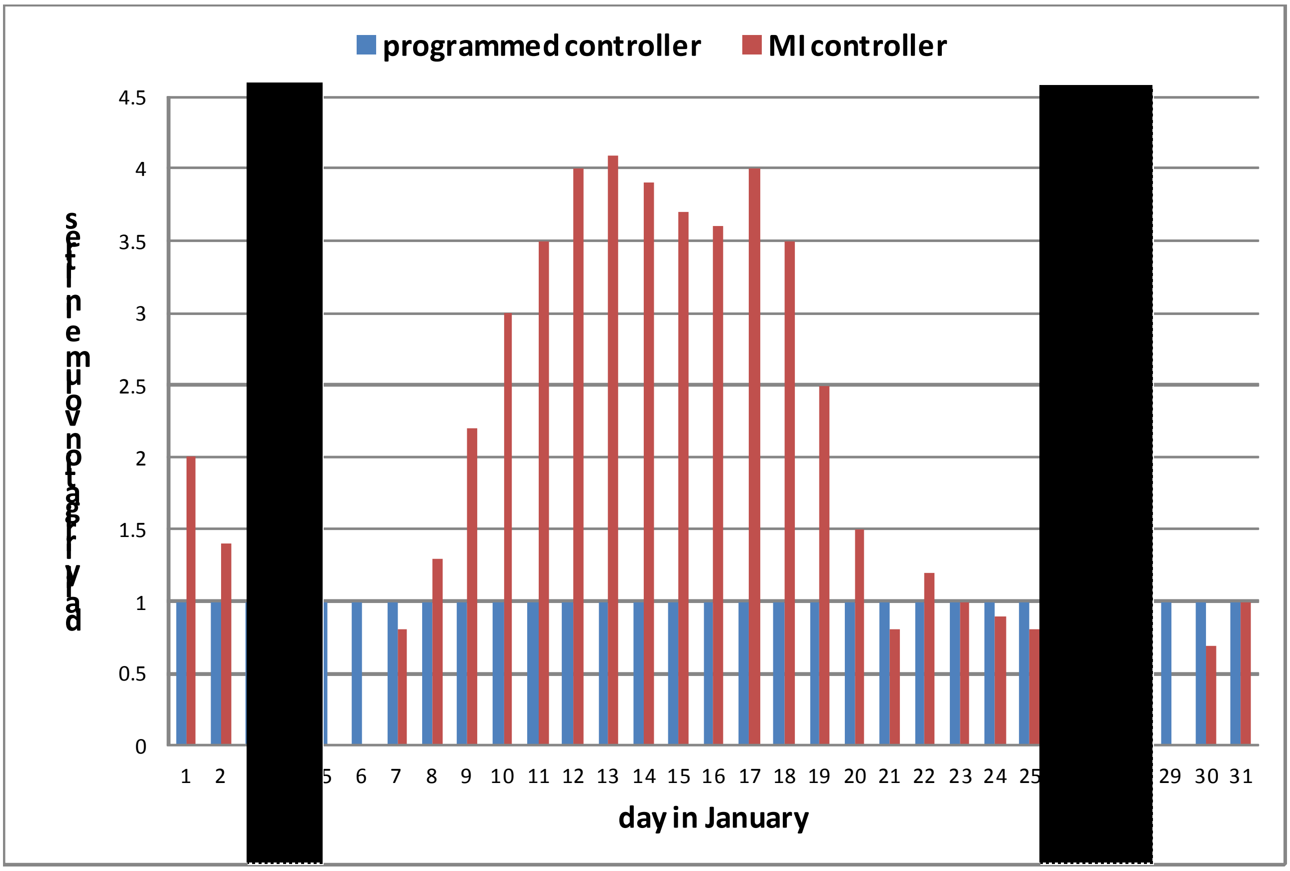
The 4-zone MI controller can be used for any drip irrigation system with up to four irrigation zones. In this section we are looking at upgrading pressurised drip irrigation. However, the same upgrading process can be applied to 4-zone gravity feed drip irrigation.



4-zone MI controller

We will now compare the 4-zone MI controller with a standard 4-zone programmed controller.

Suppose you are using a programmed controller and you need to go away for the whole of January. So you program your controller to irrigate for 30 minutes every evening. Hence a 2 L/h dripper will emit 1 litre every evening regardless of the weather. The chart below shows daily irrigation volumes per dripper in January for the MI controller compared with the programmed controller. Notice how the MI controller adapts to the weather conditions.



It rained for 5 days in January, and so the MI controller responded by not irrigating. The programmed controller wasted a lot of water by not responding to the rain.

There was an unexpected heat wave from January 11th till January 18th and the MI controller responded by increasing the irrigation volume per dripper to almost 4 litres. The programmed controller continued to deliver only 1 litre per dripper and so many plants didn't get enough water.

I will now describe the installation of the 4-zone MI controller using a 4-zone drip irrigation system where all the drippers are pressure compensating.

Step 1. For each zone select a suitable evaporator with vertical sides. If all the drippers in the zone are the same, then the volume of water emitted by each dripper during the irrigation event is the same as the net volume of water that has evaporated from the evaporator for the zone since the previous irrigation.

Step 2 For each evaporator drill a hole in the side of the evaporator and mount a float switch. The off/on position for the float switch should be about 3 cm below the overflow level.

Step 3. For each zone position the evaporator so that a single dripper (called the control dripper) drips water into the evaporator during the irrigation. Fill the evaporator with water to the level of the float switch.

Step 4. For each zone install a 12 volt solenoid valve.

Step 5. Install a 12 volt 20 watt solar panel in a suitable location.

Step 6. Connect the 20 colour-coded electrical leads as follows. A sealed lead acid battery 12V 7.2Ah is recommended.

Connect the Bat− lead from the Charge Controller to the negative battery terminal.
Connect the Bat+ lead from the Charge Controller to the positive battery terminal.
Connect the PV− lead from the Charge Controller to the negative lead from the solar panel.
Connect the PV+ lead from the Charge Controller to the positive lead from the solar panel.
Connect the 2 white leads to the solenoid valve for zone 1 (polarity is irrelevant).
Connect the 2 green leads to the solenoid valve for zone 2.
Connect the 2 yellow leads to the solenoid valve for zone 3.
Connect the 2 pink leads to the solenoid valve for zone 4.
Connect the 2 black leads to the float switch for zone 1.
Connect the 2 blue leads to the float switch for zone 2.
Connect the 2 brown leads to the float switch for zone 3.
Connect the 2 grey leads to the float switch for zone 4.

Step 7. Switch on the MI controller to the “night only” ON position. The “battery” ON position should only be used for testing purposes or for emergency irrigation.

The irrigation starts automatically after sunset each day. The zones that need watering will be watered one at a time in order.

So the next time you take an extended holiday, the 4-zone MI controller will look after your garden regardless of the weather. The MI controller responds appropriately to temperature, humidity and rainfall. In fact the number of litres per week emitted from each dripper is directly proportional to the net evaporation rate. The MI controller can be installed in any location that has access to sunlight.

Visit the measured irrigation website for more information or to place an order
www.measuredirrigation.com.au

By using the weather to control your irrigation rather than a program, you may cut your water consumption in half by not wasting water.

8-zone pressurised drip irrigation upgrade to solar-powered automated pressurised measured irrigation

8 zones can be irrigated using two 4-zone MI controllers. A timer may be used to ensure that the first 4-zone MI controller is only available between 6pm and 12am. A second timer may be used to ensure that the second 4-zone MI controller is only available between 12am and 6am.

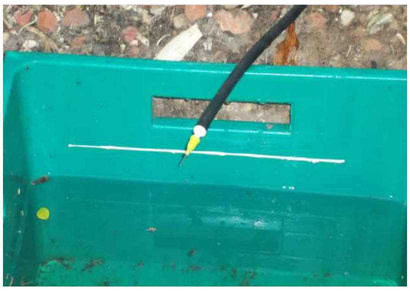
Chapter 4. Unpowered single-zone gravity feed measured irrigation

4.1 Introduction to unpowered single-zone gravity feed measured irrigation

You can use a water tank to supply water to a simple low-cost irrigation system by attaching the outlet valve on the tank to a network of polypipe with online emitters, drip tube, or drip tape attached to the polypipe. The drippers should be unregulated (non pressure compensating). All emitters should be at the same level and lower than the outlet on the tank.

A container with vertical sides is placed at a location in your garden so that one of the emitters it drips water into the container during the irrigation. This emitter is called the control nozzle. A level line is marked on the inside of the container about 3 cm below the overflow level.

When the water level is below the level line and the garden needs watering, open the valve on the tank. When the water level reaches the level line, close the valve. Due to evaporation the water level will fall and so the cycle continues indefinitely. The container is called the evaporator. When it is very hot the water evaporates more quickly and so you will open the valve sooner. And when it rains extra water enters the evaporator and so you will delay the start of the next watering. The evaporator used in the measured irrigation kits available from the measured irrigation website has a surface area of evaporation is 0.109 square metres.



Yellow control nozzle and evaporator

19 mm polypipe with a brown nozzle (nozzle 5) watering a plant

A thirsty fruit tree is being watered by a loop of Bioline and a pink nozzle (nozzle 6)

Pressure monitor tubes

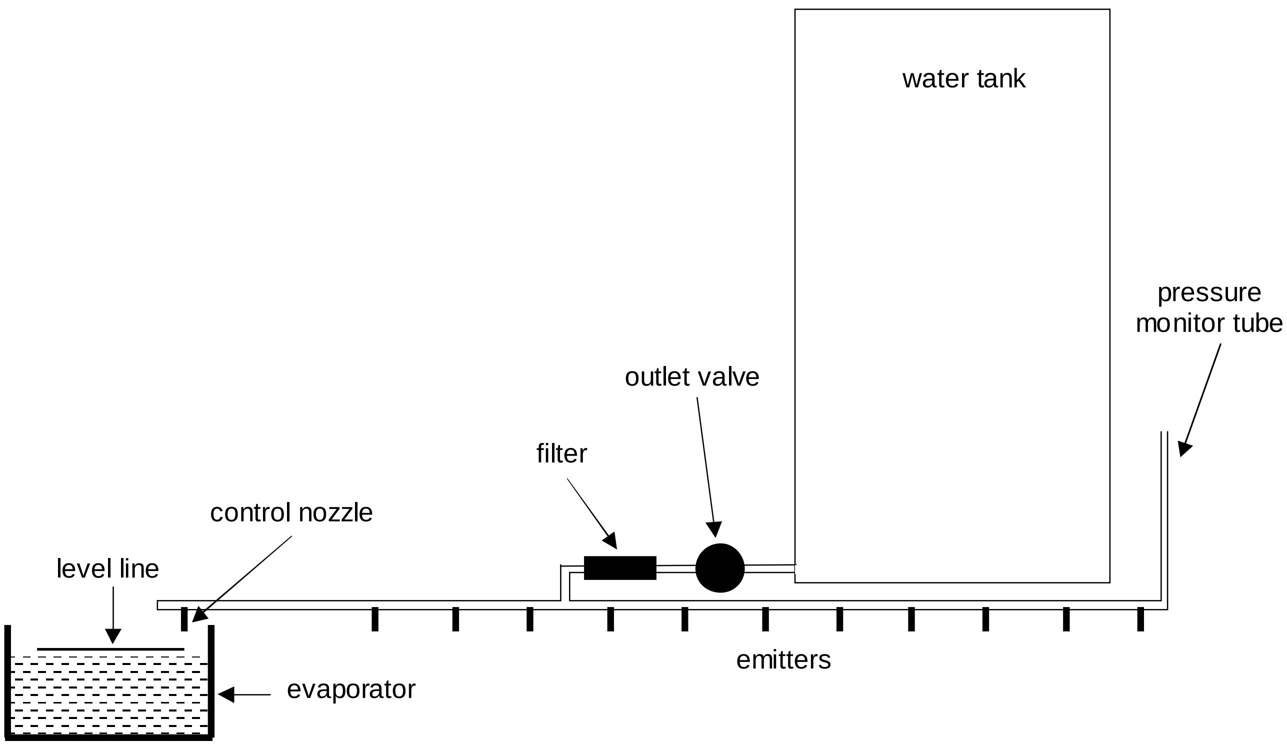
For gravity feed measured irrigation the pressure should be the same at all the drippers in the zone, and hence it is a good idea to install a number of clear vertical tubes (pressure monitor tubes) to measure the pressure at various locations within the zone. If the variations in pressure are unacceptable, the diameter of the polypipe within the zone can be increased.

Using mains pressure

Unpowered single-zone measured irrigation can be connected to mains pressure. Adjust the inlet valve so that the head of water in the pressure monitor tube is approximately 1 metre.

Pressure monitor tube indicating the water pressure in the zone

4.2 Schematic diagram of unpowered single-zone gravity feed measured irrigation



4.3 Application rates (litres per week) for unpowered single-zone gravity feed measured irrigation

By using irrigation to maintain the water level at the level line, the volume of water entering the evaporator must match the volume of water that evaporates, assuming that there is no overflow.

Monthly statistics for evaporation and rainfall in Australia are available from the Bureau of Meteorology (BOM). Provided you have access to historical data for the mean monthly evaporation and the mean monthly rainfall in your locality, this information can be used to predict the application rate (litres per week) for each of the nozzles in Table 1.

$$w_i = N_E * A * max(0, e_i - r_i) * 7 / n_i \qquad i = 1, 2, 3, \ldots, 12 \qquad (2)$$

where

- w_i is an estimate of the weekly application rate for the nozzle in month *i,*
- N_E is the nozzle ratio of the emitter nozzle to the control nozzle,
- *A* is the surface area of evaporation,
- e_i is the BOM mean monthly evaporation in month *i,*
- r_i is the BOM mean monthly rainfall in month *i,* and
- n_i is the number of days in month *i.*

Formula (2) is referred to as the **measured irrigation level formula** and it is derived in Appendix 2.

Note that these estimates of the application rate for the nozzle depend only on the nozzle ratio, the surface area of evaporation, and BOM data. The estimates are independent of pressure, flow rate, irrigation frequency, and the duration of the irrigation event. Note that the estimate is zero whenever r_i is greater than e_i.

4.4 Measured Irrigation Nozzle Selector Tool for unpowered single-zone gravity feed measured irrigation

The Measured Irrigation Nozzle Selector Tool is a powerful interactive spreadsheet used to select the appropriate nozzles for a broad range of measured irrigation applications. If you decide to use the Measured Irrigation Nozzle Selector Tool, it is preferable that the evaporator be exposed to full sun. For unpowered single-zone gravity feed measured irrigation, the nozzle selector tool is the implementation of measured irrigation level formula (2) above. A picture of the *litres per week with BOM data* worksheet is shown at the end of this section. There is also a picture of the *litres per week without BOM data* worksheet.

Because the irrigation is operated manually, you may ignore the references to control volume, irrigation volumes and irrigation frequencies in the spreadsheet.

Using the nozzle selector tool for unpowered gravity feed measured irrigation with BOM data

1. Enter the control nozzle number into the relevant cell in the *litres per week with BOM data* worksheet (for example, the green nozzle is nozzle number 2 and the yellow nozzle is nozzle number 3). If you are using more than one nozzle for the control nozzle, adjust the relevant cell in the *litres per week with BOM data* worksheet. If you are using your own evaporator, you will need to measure the surface area of evaporation and adjust the relevant cell in the *litres per week with BOM data* worksheet. Leave the other parameters at their default values.
2. Using the BOM (Bureau of Meteorology) evaporation data worksheet, find the BOM weather station nearest to your property (the weather stations are in alphabetical order). Copy and paste the mean monthly evaporation data January to December into the *litres per week* worksheet.
3. Go to the BOM website www.bom.gov.au/climate/data/index.shtml . Enter the location of your property and follow the prompts to find the weather station nearest to your property and then click *Get Data.* At the bottom of the data you there is the heading *Summary statistics for all years.* Copy and paste the mean monthly rainfall data January to December into the *litres per week* worksheet.
4. For each plant estimate the number of litres per week required during the hottest month of the year. Note that the hottest month is the month that has the maximum net evaporation (evaporation minus rainfall). Then use the *litres per week with BOM data* worksheet to select the corresponding emitter nozzle or nozzles. Note that measured irrigation does not help you decide how many litres per week a plant requires. However, once you have made a decision, the worksheet enables you to accurately implement your decision.
5. The *litres per week with BOM data* worksheet provides an estimate of the application rate in litres per week for each emitter nozzle for each month of the year.

Using the nozzle selector tool for unpowered gravity feed measured irrigation without BOM data

1. Enter the control nozzle number into the relevant cell in the *litres per week without BOM data* worksheet (for example, the green nozzle is nozzle number 2 and the yellow nozzle is nozzle number 3). If you are using more than one nozzle for the control nozzle, adjust the relevant cell in the *litres per week without BOM data* worksheet. If you are using your own evaporator, you will need to measure the surface area of evaporation and adjust the relevant cell in the *litres per week without BOM data* worksheet. Leave the other parameters at their default values.
2. Estimate of net evaporation in mm for the hottest month of the year and enter this value in the relevant cell in the *litres per week without BOM data* worksheet (measure the fall in the water level in a container with vertical sides exposed to full sun). Enter the number of days in the hottest month in the relevant cell in the *litres per week without BOM data* worksheet.
3. For each plant estimate the number of litres per week required during the hottest month of the year. Then use the *litres per week without BOM data* worksheet to select the corresponding emitter nozzle or nozzles. Note that measured irrigation does not help you decide how many litres per week a plant requires. However, once you have made a decision, the worksheet enables you to accurately implement your decision.

Litres per week with BOM data worksheet

The irrigation volumes and application rates in this worksheet are based on monthly evaporation and rainfall data.

enter control nozzle number	1		
enter control volume in litres	1.000	emitter nozzle correction factor	1.000
enter surface area of evaporation in m^2	0.109	head ratio emitter nozzle to control nozzle	1.000
enter number of identical control nozzles	2	emitter discharge exponent	0.500

	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec	
copy and paste the average monthly evaporation in mm (in Australia use the BOM evaporation data worksheet)	284.7	239.8	203.2	130.9	82.4	57.7	61.1	85.2	120.6	175.0	220.3	257.1	Adelaide Airport
copy and paste the average monthly rainfall in mm	17.5	19.2	22.1	35	54.1	56.9	59.7	50.5	45.1	36.6	24.8	23.4	Adelaide Airport
nett evaporation in mm	267.2	220.6	181.1	95.9	28.3	0.8	1.4	34.7	75.5	138.4	195.5	233.7	

In Australia, monthly rainfall data is available from the Bureau of Meteorology website: http://www.bom.gov.au/climate/data/index.shtml

Note that Miniscape refers to a Netafim Miniscape (Landline 8) dripper, Bioline refers to a Netafim Bioline dripper

waterings per week Jan	waterings per week Feb	waterings per week March	waterings per week April	waterings per week May	waterings per week June	waterings per week June	waterings per week Aug	waterings per week Sept	waterings per week Oct	waterings per week Nov	waterings per week Dec
6.6	6.0	4.5	2.4	0.7	0.0	0.0	0.9	1.9	3.4	4.8	5.8

nozzle	irrigation litres	L/week Jan	L/week Feb	L/week March	L/week April	L/week May	L/week June	L/week July	L/week Aug	L/week Sept	L/week Oct	L/week Nov	L/week Dec		L/year	average L/week
Miniscape (nozzle N1)	0.50	3.29	3.01	2.23	1.22	0.35	0.01	0.02	0.43	0.96	1.70	2.41	2.88	MS	80	1.54
green (nozzle N2)	1.04	6.83	6.24	4.63	2.53	0.72	0.02	0.04	0.89	1.99	3.54	5.00	5.97	green	167	3.21
yellow (nozzle N3)	1.57	10.30	9.42	6.98	3.82	1.09	0.03	0.05	1.34	3.01	5.34	7.54	9.01	yellow	252	4.84
Bioline (nozzle N4)	2.00	13.15	12.02	8.91	4.88	1.39	0.04	0.07	1.71	3.84	6.81	9.62	11.50	Bioline	321	6.18
brown (nozzle N5)	2.65	17.42	15.92	11.81	6.46	1.84	0.05	0.09	2.26	5.09	9.02	12.74	15.23	brown	425	8.18
pink (nozzle N6)	4.50	29.59	27.05	20.06	10.98	3.13	0.09	0.16	3.84	8.64	15.33	21.65	25.88	pink	723	13.90
white (nozzle N7)	7.14	46.98	42.94	31.84	17.42	4.98	0.15	0.25	6.10	13.72	24.33	34.37	41.09	white	1147	22.06
purple (nozzle N8)	8.99	59.14	54.06	40.08	21.93	6.26	0.18	0.31	7.68	17.27	30.63	43.27	51.73	purple	1444	27.77
orange (nozzle N9)	12.59	82.77	75.66	56.10	30.70	8.77	0.26	0.43	10.75	24.17	42.87	60.56	72.39	orange	2021	38.86
olive (nozzle N10)	16.26	106.92	97.73	72.46	39.65	11.32	0.33	0.56	13.88	31.22	55.38	78.23	93.51	olive	2610	50.20
small rivet (nozzle N11)	32.54	214.02	195.63	145.06	79.37	22.67	0.66	1.12	27.79	62.49	110.85	156.59	187.19	N10	5225	100.49
medium rivet (nozzle N12)	49.37	324.69	296.79	220.07	120.42	34.39	1.00	1.70	42.17	94.80	168.18	237.57	283.99	N11	7927	152.45
large rivet (nozzle N13)	65.74	432.36	395.20	293.04	160.35	45.79	1.34	2.27	56.15	126.24	223.95	316.34	378.16	N12	10556	203.00
5/32 washer (nozzle N14)	121.00	795.76	727.37	539.35	295.13	84.28	2.46	4.17	103.34	232.35	412.18	582.23	696.00	N13	19429	373.63
5mm washer (nozzle N15)	218.29	1435.57	1312.19	972.99	532.41	152.05	4.44	7.52	186.43	419.16	743.57	1050.35	1255.59	N14	35050	674.03
1/4 washer (nozzle N16)	342.86	2254.82	2061.03	1528.25	836.25	238.82	6.98	11.81	292.82	658.36	1167.92	1649.77	1972.13	N15	55052	1058.69
7 mm (nozzle N17)	485.71	3194.33	2919.80	2165.02	1184.68	338.32	9.88	16.74	414.83	932.68	1654.55	2337.17	2793.85	N16	77990	1499.81

Litres per week without BOM data worksheet

Measured irrigation nozzle selector

The irrigation volumes and application rates in this worksheet are based on your estimate of the nett evaporation in the hottest month.

enter control nozzle number	1
enter control volume in litres	1.000
surface area of evaporation in m^2	0.109
emitter nozzle correction factor	1.000
head ratio emitter nozzle to control nozzle	1.000
emitter discharge exponent	0.500
estimate of nett evaporation in mm for the hottest month	250
number of days in the hottest month	31

Note that the hottest month is the month that has the maximum nett evaporation (evaporation minus rainfall)

waterings per week in hottest month

6.15

nozzle	irrigation volume in litres	L/week in hottest month
MS (nozzle N1)	1.00	6.15
green (nozzle N2)	2.08	12.78
yellow (nozzle N3)	3.13	19.28
Bioline (nozzle N4)	4.00	24.61
brown (nozzle N5)	5.30	32.59
pink (nozzle N6)	9.00	55.38
white (nozzle N7)	14.29	87.90
purple (nozzle N8)	17.99	110.67
orange (nozzle N9)	25.17	154.89
olive (nozzle N10)	32.51	200.07
small rivet (nozzle N11)	65.09	400.49
medium rivet (nozzle N12)	98.74	607.59
large rivet (nozzle N13)	131.49	809.06
5/32 washer (nozzle N14)	242.00	1489.08
5mm washer (nozzle N15)	436.57	2686.32
1/4 washer (nozzle N16)	685.71	4219.35
7 mm (nozzle N17)	971.43	5977.42

Note that MS refers to a Netafim Miniscape (Landline 8) dripper

Note that Bioline refers to a Netafim Bioline dripper

For more information go to the measured irrigation website: http://www.measuredirrigation.com.au/

4.5 Installing unpowered single-zone gravity feed measured irrigation

It is recommended that you watch the YouTube video entitled *Think twice before you buy a pump for your rainwater tank:* https://www.youtube.com/watch?v=oN53adj_3sk

Unpowered single-zone gravity feed measured irrigation is installed in 5 simple steps:

Step 1. Attach the filter after the outlet valve on the water tank. The irrigation is gravity feed and so you can only water plants that are lower than the outlet valve.

Step 2. Connect a network of polypipe to the filter so that all the plants to be watered are close to the nearest polypipe. Do not use hose clamps, they are not needed. To minimise head loss, 19 mm polypipe is recommended.

Step 3. For each plant, punch a hole in the nearest polypipe and insert a take-off adaptor into the hole. Cut a suitable length of 6 mm flexible tube to deliver water to the plant. Attach one end of the tube to the take-off adaptor and the other end to an emitter nozzle or a length of Miniscape or Bioline drip tube. Don’t worry if you don’t know what nozzle to use - you can change a nozzle at any time if a plant is getting too much or too little water. The Measured Irrigation Nozzle Selector Tool will help you to select a suitable emitter nozzle. If you are using drip tube it may be connected directly to the polypipe without using flexible tube.

Step 4. Following the procedure in Step 3, attach the control nozzle to a length of flexible tube so that it delivers water to the evaporator. You may need to dig a hole for the evaporator so that control nozzle is at the same level as the other nozzles.

Step 5. Connect a pressure monitor tube to the polypipe. A pressure monitor tube is used to check the pressure at any point in the zone to be confident that everything is working according to your expectations.

Level ground

To ensure that the pressure is the same at all emitter nozzles, the nozzles should be at the same level and you need to minimise any head loss between the nozzles. You can use pressure monitor tubes to check the pressure at any emitter nozzle and if variations in pressure are unacceptable you can either adjust the levels of the nozzles or increase the diameter of the polypipe.

Sloping ground

Position a length of polypipe so that it follows a contour line higher than all the plants to be watered by emitter nozzles attached to the length of polypipe. A length of 6 mm tube delivers the water from the nozzle to the plant at a lower level. Note that there is a small breather hole in the black tube protecting the nozzle to ensure that the nozzle remains at atmospheric pressure.

4.6 Unpowered single-zone gravity feed measured irrigation kit

The kit consists of the following components and is available from the measured irrigation website.

	quantity
Measured Irrigation Manual	1
evaporator	1
filter – 120 mesh	1
inlet valve	1
pressure monitor tubes	2
6 mm flexible tube (metres)	10
colour-coded nozzles (6 green N2, 10 yellow N3, 10 brown N5, 9 pink N6, 8 white N7, 4 purple N8, 3 orange N9, 2 olive N10)	52
Netafim Miniscape drip tube with 0.15m dripper spacing (metres)	4
Netafim Bioline drip tube with 0.3m dripper spacing (metres)	4
5 mm goof plugs	10
red 6 mm take-off adaptors	50
5 mm hole punch tool	1

Except for the polypipe and the polypipe fittings, the kit includes everything you need to irrigate al least 50 plants.

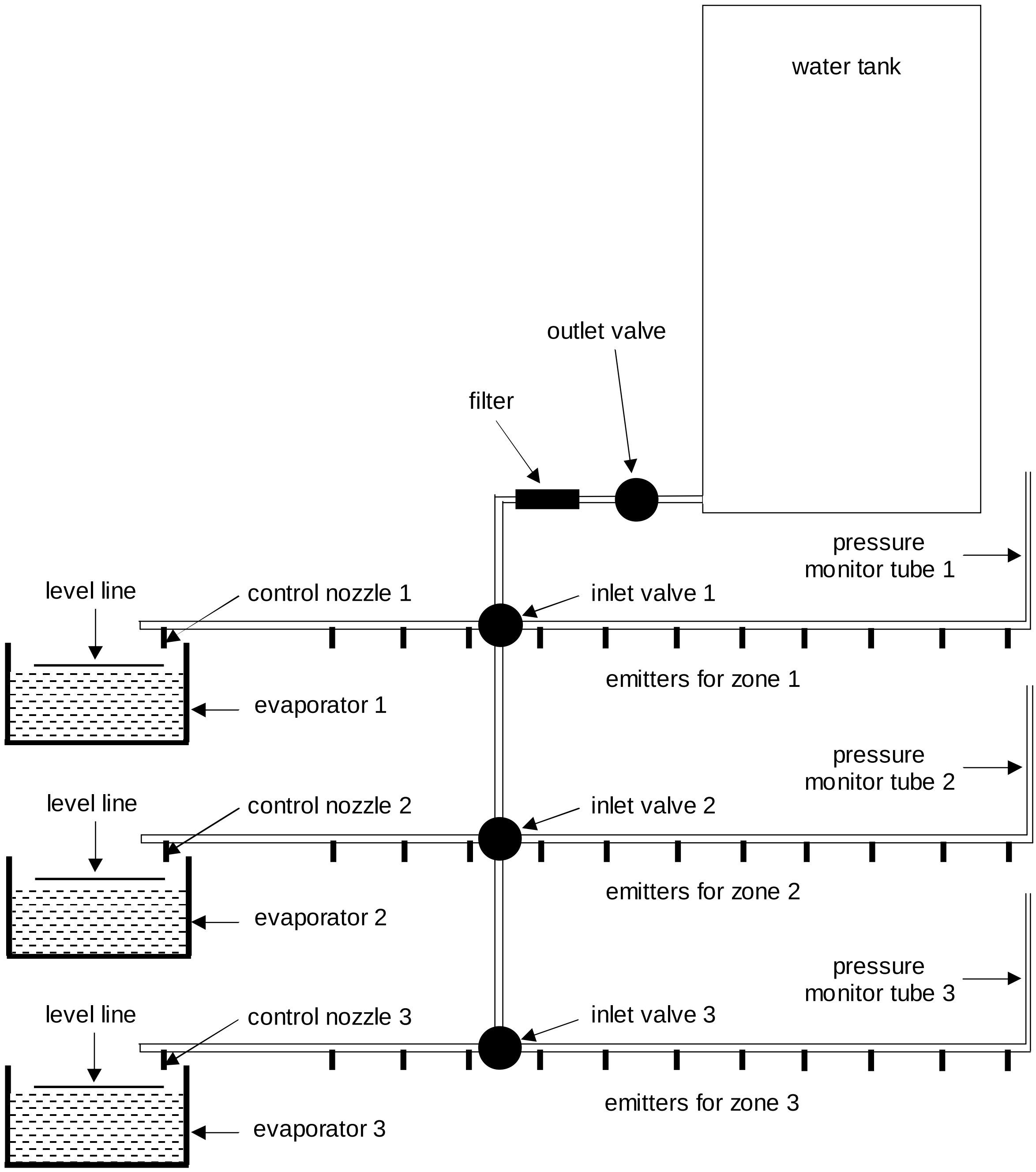
Unpowered single-zone measured irrigation kit

Chapter 5. Unpowered multi-zone gravity feed measured irrigation

Unpowered multi-zone gravity feed measured irrigation is a simple extension of unpowered single-zone gravity feed measured irrigation whereby the plants are grouped into zones. Each zone is connected to the water tank and has its own inlet valve, evaporator, control nozzle and pressure monitor tube. The emitters in each zone should be at the same level and lower than the outlet on the tank.

When each zone needs watering, open the inlet valve for the zone. When the water level in the zone's evaporator reaches the level line, close the inlet valve.

Schematic diagram of unpowered single-zone gravity feed measured irrigation



Installing unpowered multi-zone gravity feed measured irrigation

Step 1. Attach the filter after the outlet valve on the water tank.

Step 2. For each zone set up a network of polypipe so that all the plants in the zone are close to the nearest polypipe. Use polypipe to connect the filter to the inlet valve for the zone.

Step 3. For each plant in each zone, punch a hole in the nearest polypipe and insert a take-off adaptor into the hole. Cut a suitable length of 6 mm flexible tube to deliver water to the plant. Attach one end of the tube to the take-off adaptor and the other end to an emitter nozzle or a length of Miniscape or Bioline drip tube. The Measured Irrigation Nozzle Selector Tool will help you to select a suitable nozzle. If you are using drip tube it may be connected directly to the polypipe without using flexible tube.

Step 4. For each zone attach the control nozzle to a length of flexible tube so that it delivers water to the evaporator. You may need to dig a hole for the evaporator so that control nozzle is at the same level as the other nozzles in the zone.

Step 5. For each zone connect a pressure monitor tube to the polypipe.

Zone on level ground

To ensure that the pressure is the same at all emitter nozzles in the zone, the nozzles should be at the same level and you need to minimise any head loss between the nozzles. You can use pressure monitor tubes to check the pressure at any emitter nozzle and if variations in pressure are unacceptable you can either adjust the levels of the nozzles or increase the diameter of the polypipe.

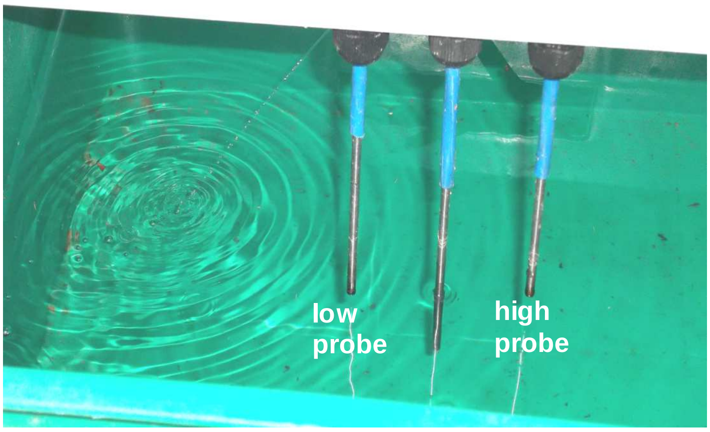
Zone on sloping ground

Position a length of polypipe so that it follows a contour line higher than all the plants in the zone to be watered by emitter nozzles attached to the length of polypipe. A length of 6 mm tube delivers the water from the nozzle to the plant at a lower level. Note that there is a small breather hole in the black tube protecting the nozzle to ensure that the nozzle remains at atmospheric pressure.

Chapter 6. Solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level

6.1 Introduction to solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level

Conventional irrigation systems use an irrigation controller to control the opening and closing of solenoids in order to control the duration of the irrigation event and the frequency of irrigation. Solar-powered automated single-zone gravity feed measured irrigation (and solar-powered automated multi-zone gravity feed measured irrigation) uses an evaporator and level sensor to control the duration of the irrigation event and the frequency of irrigation.



The level sensor has three probes as shown. During the irrigation event the water level rises as water slowly drips into the evaporator from the control nozzle. When the water level reaches the high probe on the right a solenoid valve closes and the irrigation stops. The water level then falls due to evaporation until the water level is below the low probe on the left at which point the solenoid valve opens and the irrigation recommences. The middle probe is a reference probe. This cycle continues indefinitely.

The volume of water required to raise the water level from the low probe level to the high probe level is called the **control volume**. It is also the volume of water that must evaporate between irrigation events.

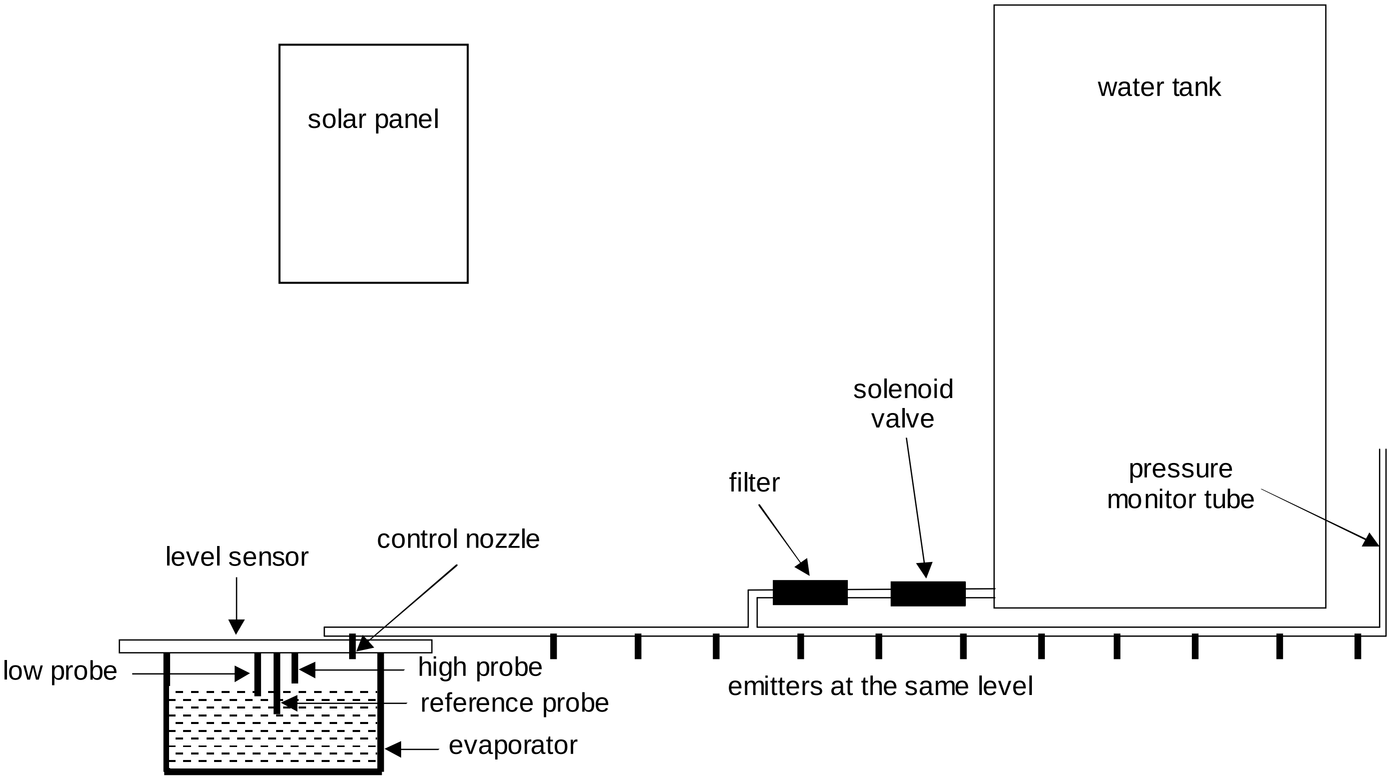
All the power required for single-zone gravity feed measured irrigation is provided by a 10 watt solar panel.

By choosing appropriate emitters, every plant in your garden will receive the desired volume of water during the irrigation event. The volume of water delivered to each plant in your garden is simply the control volume multiplied by the relevant nozzle ratio in Table 2 on page10.

As well as being completely automatic, the irrigation frequency responds to the prevailing weather conditions. During very hot weather the evaporation rate will be much greater and so the irrigation down time will be shorter. On cool overcast days, the evaporation rate will be quite small and so the irrigation down time will be longer.

See Section 13.1 for a demonstration site that uses solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level.

6.2 Schematic diagram of solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level



6.3 Application rates (litres per week) for solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level

The analysis in Section 4.3 is applicable and hence the second condition in the definition of measured irrigation:

> *The application rate for each plant throughout the year is directly proportional to the current net evaporation rate and is independent of the pressure, the flow rate, the irrigation frequency and the duration of the irrigation event.*

Monthly statistics for evaporation and rainfall in Australia are available from the Bureau of Meteorology (BOM). Provided you have access to historical data for the mean monthly evaporation and the mean monthly rainfall in your locality, this information can be used in the measured irrigation level formula (2) in Section 4.3 to estimate the application rate (litres per week) for each of the nozzles in Table 1.

$$w_i = N_E * A * max(0, e_i - r_i) * 7 / n_i \qquad i = 1, 2, 3, \dots, 12$$

where

w_i is an estimate of the weekly application rate for the nozzle in month *I*,

N_E is the nozzle ratio of the emitter nozzle to the control nozzle,

A is the surface area of evaporation,

e_i is the BOM mean monthly evaporation in month *i*,

r_i is the BOM mean monthly rainfall in month *i,and*

n_i is the number of days in month *i.*

Note that these estimates of the application rate for the nozzle depend only on the nozzle ratio, the surface area of evaporation, and BOM data. The estimates are independent of the irrigation frequency. Note that the estimate is zero whenever r_i is greater than e_i.

6.4 Irrigation volumes for solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level

The volume of water delivered by an emitter nozzle during the irrigation event is determined by the relationship between the emitter nozzle and the control nozzle.

You can ignore the flow rate and you can ignore the duration of the irrigation event, both will adjust automatically to ensure that the desired volume of water is delivered to each plant.

The high cost and high maintenance of pressurised drip irrigation systems are a consequence of the erroneous assumption that an accurate and reliable irrigation system needs to be pressurised. Gravity feed measured irrigation is accurate and reliable, and less expensive than a comparable pressurised drip irrigation system when there is no access to mains water.

With measured irrigation you can decide in advance the volume of water to be delivered to each plant in your garden, orchard or plantation during the irrigation event. Hence you know in advance the total volume of water that will be used during the irrigation event.

Nozzle formula

The **nozzle formula** states that

measured volume = control volume * nozzle ratio

where the control volume is the volume of water delivered to the evaporator during the irrigation event, and the nozzle ratio is the ratio of the flow rate of the emitter nozzle to the flow rate of the control nozzle when both nozzles are at the same pressure. All measured irrigation volumes are predicted by the nozzle formula.

For single-zone gravity feed measured irrigation with emitters at the same level (and hence the same pressure), one can apply the nozzle formula.

The number of litres of water delivered to a plant by an emitter nozzle during the irrigation event is calculated by multiplying the control volume by the nozzle ratio for the emitter nozzle in Table 2.

Nozzle ratio calibration

For any combination of emitter nozzle and control nozzle, there is a simple method to work out the nozzle ratio. Over the same period of time collect the water from the emitter nozzle in one container and the water from the control nozzle in another container. Then the nozzle ratio is simply the ratio of the water volumes in the two containers. Using this method, it is very easy to make and calibrate your own emitter nozzles suited to your particular irrigation requirements.

6.5 Measured Irrigation Nozzle Selector Tool for solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level

For solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level, the nozzle selector tool is the implementation of measured irrigation level formula (2) and the nozzle formula. If you decide to use the Measured Irrigation Nozzle Selector Tool, it is preferable that the evaporator be exposed to full sun. Pictures of the *litres per week with BOM data* worksheet and the *litres per week without BOM data* are shown at the end of Section 4.4.

Using the nozzle selector tool for solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level and with BOM data

1. Enter the control nozzle number into the relevant cell in the *litres per week with BOM data* worksheet. If you are using more than one nozzle for the control nozzle, adjust the relevant cell in the *litres per week with BOM data* worksheet. Enter the control volume into the relevant cell in the *litres per week with BOM data* worksheet. If you are using your own evaporator, you will need to measure the surface area of evaporation and adjust the relevant cell in the *litres per week with BOM data* worksheet. Leave the other parameters at their default values.
2. Using the BOM (Bureau of Meteorology) evaporation data worksheet, find the BOM weather station nearest to your property (the weather stations are in alphabetical order). Copy and paste the mean monthly evaporation data January to December into the *litres per week* worksheet.
3. Go to the BOM website www.bom.gov.au/climate/data/index.shtml . Enter the location of your property and follow the prompts to find the weather station nearest to your property and then click *Get Data.* At the bottom of the data you there is the heading *Summary statistics for all years.* Copy and paste the mean monthly rainfall data January to December into the *litres per week* worksheet.
4. For each plant estimate the number of litres per week required during the hottest month of the year. Then use the *litres per week with BOM data* worksheet to select the corresponding emitter nozzle or nozzles. Note that measured irrigation does not help you decide how many litres per week a plant requires. However, once you have made a decision, the worksheet enables you to accurately implement your decision.
5. The *litres per week with BOM data* worksheet provides an estimate of the application rate in litres per week for each emitter nozzle for each month of the year. It also provides an estimate of the irrigation frequency (in waterings per week) for each month of the year, and an estimate of the irrigation volume for each emitter nozzle.

Using the nozzle selector tool for solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level and without BOM data

1. Enter the control nozzle number into the relevant cell in the *litres per week without BOM data* worksheet. If you are using more than one nozzle for the control nozzle, adjust the relevant cell in the *litres per week without BOM data* worksheet. Enter the control volume into the relevant cell in the *litres per week without BOM data* worksheet. If you are using your own evaporator, you will need to measure the surface area of evaporation and adjust the relevant cell in the *litres per week without BOM data* worksheet. Leave the other parameters at their default values.
2. Estimate of net evaporation in mm for the hottest month of the year and enter this value in the relevant cell in the *litres per week without BOM data* worksheet (measure the fall in the water level in a container with vertical sides exposed to full sun). Enter the number of days in the hottest month in the relevant cell in the *litres per week without BOM data* worksheet.
3. For each plant estimate the number of litres per week required during the hottest month of the year. Then use the *litres per week without BOM data* worksheet to select the corresponding emitter nozzle or nozzles. Note that measured irrigation does not help you decide how many litres per week a plant requires. However, once you have made a decision, the worksheet enables you to accurately implement your decision.
4. The *litres per week without BOM data* worksheet provides an estimate of the irrigation frequency (in waterings per week) for the hottest month of the year, and an estimate of the irrigation volume for each emitter.

6.6 Installing solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level – level sensor option

It is recommended that you watch the YouTube video entitled *A major advance in gravity feed irrigation*

https://www.youtube.com/watch?v=sGb4WMKybBA

Step 1. Attach the filter after the outlet valve on the water tank. The irrigation is gravity feed and so you can only water plants that are lower than the outlet valve.

Step 2. Connect a network of polypipe to the filter so that all the plants to be watered are close to the nearest polypipe. Do not use hose clamps, they are not needed. To minimise head loss, 19 mm polypipe is recommended. As the distance from the water tank to the zone increases, you may need to increase the diameter of the polypipe to compensate for head loss.

Step 3. For each plant, punch a hole in the nearest polypipe and insert a take-off adaptor into the hole. Cut a suitable length of 6 mm flexible tube to deliver water to the plant. Attach one end of the tube to the take-off adaptor and the other end to an emitter nozzle or a length of Miniscape or Bioline drip tube. Don't worry if you don't know what nozzle to use - you can change a nozzle at any time if a plant is getting too much or too little water. The Measured Irrigation Nozzle Selector Tool will help you to select a suitable emitter nozzle. If you are using drip tube it may be connected directly to the polypipe without using flexible tube.

Step 4. Position the evaporator so that it is exposed to full sun. Following the procedure in Step 3, attach the control nozzle to a length of flexible tube so that it delivers water to the evaporator. You may need to dig a hole for the evaporator so that control nozzle is at the same level as the other nozzles.

Step 5. Connect a pressure monitor tube to the polypipe

Step 6. Install a 10 watt solar panel in a suitable location.

Step 7. Install the solenoid valve after the filter.

Step 8. Place the level sensor on the evaporator. It is recommended that you secure the level sensor to the evaporator (using a cable tie for example) to prevent the level sensor accidentally falling into the water. Connect the colour coded leads from the valve controller as follows:
blue lead connects to the positive lead from the battery
green lead connects to the negative lead from the battery
white lead connects to the white lead from the level sensor (reference probe)
pink lead connects to the red (or yellow) lead from the level sensor (high probe)
brown lead connects to the black lead from the level sensor (low probe)
yellow lead connects to one lead from the solenoid valve
grey lead connects to the other lead from the solenoid valve
red leads connects to the Load positive lead from the charge controller
black leads connects to the Load negative lead from the charge controller

Step 9. The Measured Irrigation Nozzle Selector Tool will help you choose a control volume that will generate an appropriate irrigation frequency for your garden. The control volume can be adjusted by adjusting the gap between the high and low probes (both probes are adjustable).

Step 10. For normal operation the switch on the valve controller should be set to **night only ON** so that the irrigation starts after sunset. You may set the switch to **battery ON** for testing or demonstration purposes or when the garden urgently needs to be watered. To start the irrigation manually simply raise the level sensor so that the low probe is out of the water. If you decide that you garden needs an extra watering, then remove some water from the evaporator to start watering.

Level ground – see discussion in Section 4.5

Sloping ground – see discussion in Section 4.5

Note

In order for the Measured Irrigation Nozzle Selector Tool to accurately predict the volume of water delivered by each nozzle, you need to accurately measure the control volume. The following method is recommended. At the end of the irrigation event slowly take water from the evaporator and transfer it to another container. As the water level gets close to the low level, carefully remove the water with a syringe until the water level separates from the low probe and the valve controller starts the next irrigation event. The volume of water in the container is the control volume.

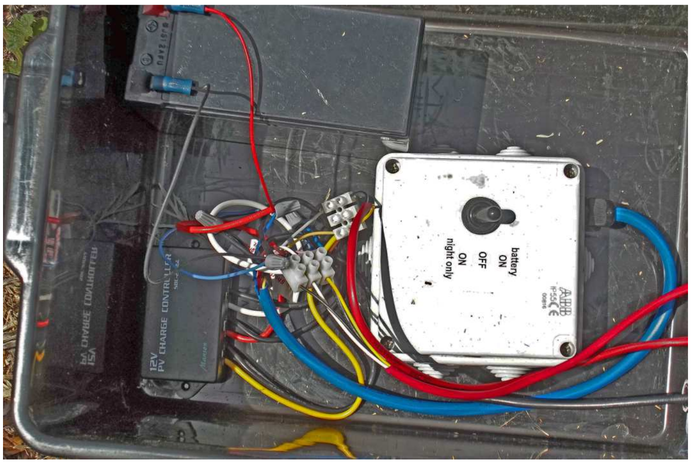
6.7 Solar-powered automated single-zone gravity feed measured irrigation kit – level sensor option

The kit consists of the following components and is available from the measured irrigation website.

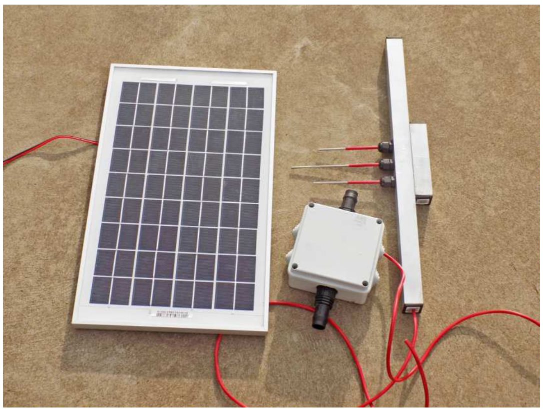
	Quantity
Measured Irrigation Manual	1
monocrystalline solar panel 12V 10W	1
charge controller	1
sealed lead acid battery 12V 7.2Ah	1
solenoid valve 12V 5W	1
valve controller	1
waterproof control box	1
level sensor with 3 probes	1
evaporator	1
filter – 120 mesh	1
inlet valve	1
pressure monitor tubes	2
6 mm flexible tube (metres)	10
colour-coded nozzles (6 green N2, 10 yellow N3, 10 brown N5, 9 pink N6, 8 white N7, 4 purple N8, 3 orange N9, 2 olive N10)	52
Netafim Miniscape drip tube with 0.15m dripper spacing (metres)	4
Netafim Bioline drip tube with 0.3m dripper spacing (metres)	4
5 mm goof plugs	10
red 6 mm take-off adaptors	50
5 mm hole punch tool	1
electrical irrigation cable - 3 strand (metres)	10
electrical irrigation cable connectors	8

Except for the polypipe and the polypipe fittings, the kit includes everything you need to irrigate al least 50 plants.

Solar-powered automated single-zone measured irrigation kit: components from unpowered kit



Solar-powered automated single-zone measured irrigation kit: waterproof control box with battery, charge controller and valve controller



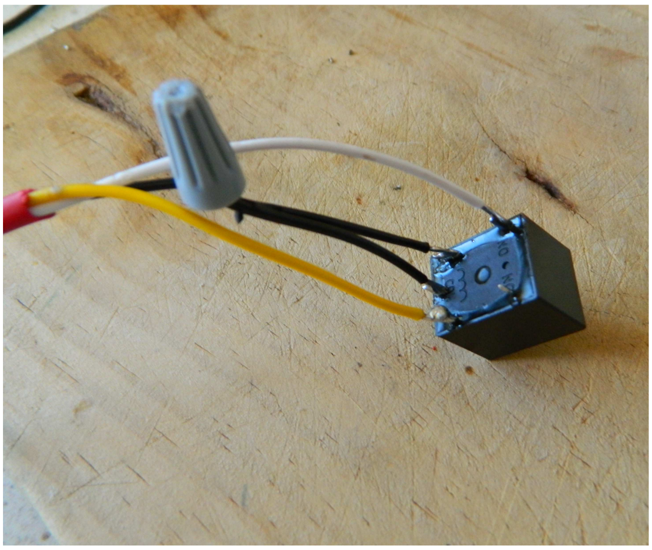
Solar-powered automated single-zone measured irrigation kit: solar panel, solenoid valve and level sensor

6.8 Installing solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level – float switch option

The cost of solar-powered automated single-zone measured irrigation can be significantly reduced by replacing the level sensor and the valve controller by a float switch and a power relay. The installation steps 1 to 7 remain the same. Steps 8 to 10 are replaced by the following steps.

Step 8 Install the float switch on the side of the evaporator so that the irrigation stops automatically when the water level reaches the switch.

Step 9 Connect the COM pin on the relay and one of the COIL pins on the relay to the Load negative lead from the charge controller.
Connect the other COIL pin on the relay to one of the leads from the float switch.
Connect the NO (normally open) pin on the relay to the negative lead from the pump (or solenoid valve).
Connect the positive lead from the pump (or solenoid valve) and the other lead from the float switch to the Load positive lead from the charge controller.
Connect the positive lead from the solar panel to the corresponding lead from the charge controller.
Connect the negative lead from the solar panel to the corresponding lead from the charge controller.
Connect the positive lead from the battery to the corresponding lead from the charge controller.
Connect the negative lead from the battery to the corresponding lead from the charge controller.



If you are using a relay with pins (for a printed circuit board), you can use solder to connect a length of insulated wire to a pin.

One way of protecting the relay from the weather is to house the relay in a short length of vertical polypipe with a plug at the top.

The irrigation will start automatically at sunset provided that the float switch is on. The irrigation will stop when the water level has risen and turned off the float switch (or the sun rises).

If there is no rain, irrigation will occur every evening at sunset. This may be a problem if less frequent automatic irrigation is desirable, and in this case the level sensor option is preferable.

6.9 Solar-powered automated single-zone gravity feed measured irrigation kit – float switch option

The kit consists of the following components and is available from the measured irrigation website.

	quantity
Measured Irrigation Manual	1
monocrystalline solar panel 12V 10W	1
charge controller	1
sealed lead acid battery 12V 7.2Ah	1
solenoid valve 12V 5W	1
horizontal float switch	1
10A power relay	1
evaporator	1
filter – 120 mesh	1
inlet valve	1
pressure monitor tubes	2
6 mm flexible tube (metres)	10
colour-coded nozzles (6 green N2, 10 yellow N3, 10 brown N5, 9 pink N6, 8 white N7, 4 purple N8, 3 orange N9, 2 olive N10)	52
Netafim Miniscape drip tube with 0.15m dripper spacing (metres)	4
Netafim Bioline drip tube with 0.3m dripper spacing (metres)	4
5 mm goof plugs	10
red 6 mm take-off adaptors	50
5 mm hole punch tool	1
electrical irrigation cable - 3 strand (metres)	10
electrical irrigation cable connectors	8

Except for the polypipe and the polypipe fittings, the kit includes everything you need to irrigate al least 50 plants.

Float switch, solenoid valve and charge controller

Chapter 7. Solar-powered automated single-zone gravity feed measured irrigation with emitters at different levels

7.1 Introduction to solar-powered automated single-zone gravity feed measured irrigation with emitters at different levels

So far it has been required that all the emitters within a zone be at the same level. For this implementation of measured irrigation the emitters are allowed to be at different levels. In order to control the application rate for emitters at different levels, this implementation assumes the head of water at the control nozzle is maintained at a constant level.

When an emitter nozzle and the control nozzle are at the same pressure, estimates of the application rate are obtained from the measured irrigation level formula (2) in Section 4.3, namely,

$$w_i = N_E * A * max(0, e_i - r_i) * 7 / n_i \qquad i = 1, 2, 3, \dots , 12$$

where

w_i is an estimate of the weekly application rate for the nozzle in month i,

N_E is the nozzle ratio of the emitter nozzle to the control nozzle,

A is the surface area of evaporation,

e_i is the BOM mean monthly evaporation in month i,

r_i is the BOM mean monthly rainfall in month i, *and*

n_i is the number of days in month i.

When the emitter nozzle and the control nozzle are not at the same level, the emitter flow equation (1) in Appendix 1 can be used to show that

$$w_i = N_E * A * max(0, e_i - r_i) * 7 / n_i * (H_E / H_C)^x \qquad i = 1, 2, 3, \dots , 12 \qquad (3)$$

where

H_E is the head of water at the emitter nozzle,

H_C is the head of water at the control nozzle, and

x is the emitter discharge exponent.

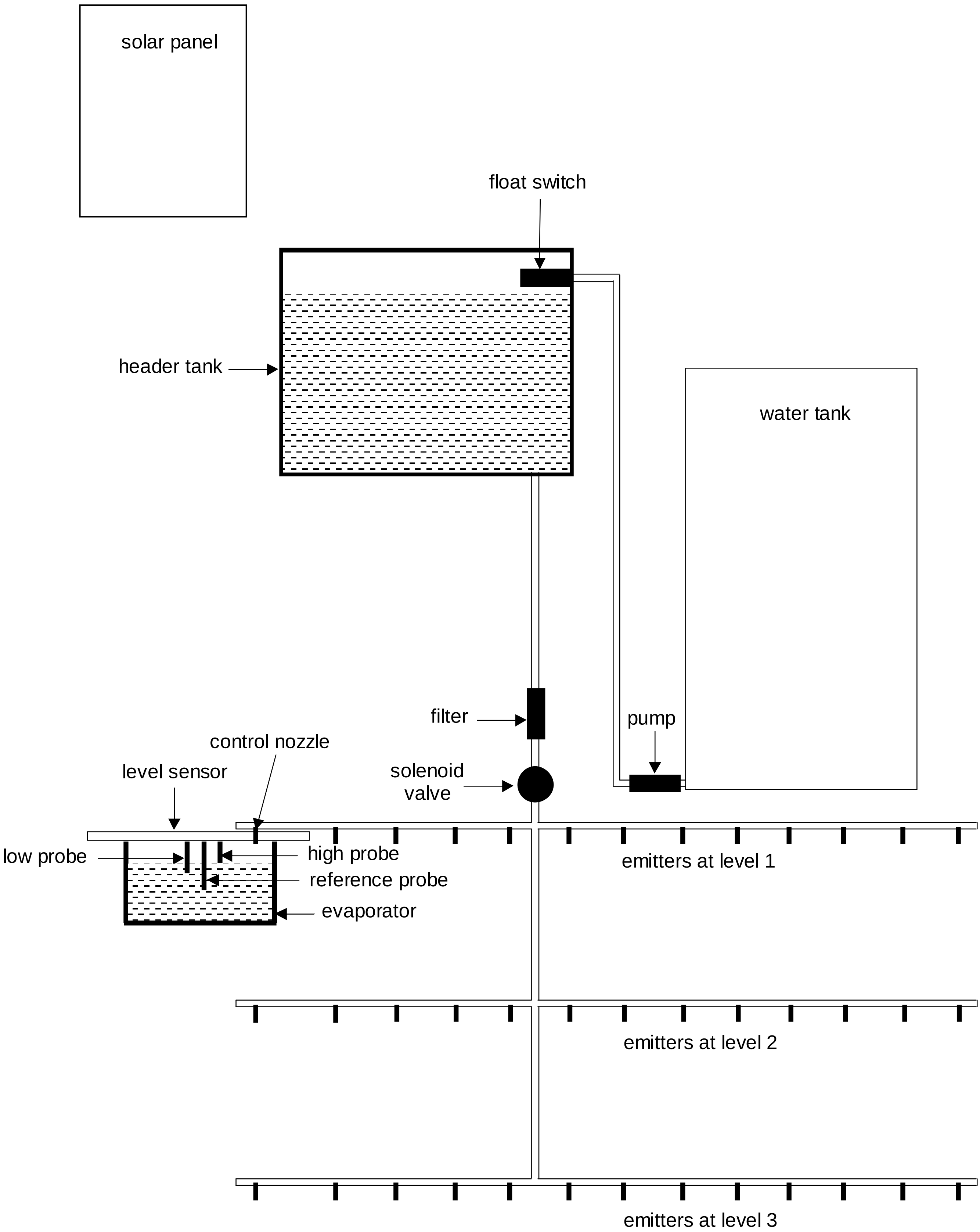
Formula (3) is called the **measured irrigation slope formula**. After measured irrigation has been established in your garden, you can use the above formula to estimate the application rate in litres per week for each emitter for each month.

All of the nozzles available from the measured irrigation website have an emitter discharge exponent of 0.5.

To apply the measured irrigation slope formula, the head of water at the control nozzle needs to remain constant for the duration of the irrigation event. If the water supply is a dam or reservoir at a higher level, then the head of water at the control nozzle is relatively constant during the irrigation event. However, if the water supply is a tank then the water level in the tank will fall during the irrigation event. One solution is to use a header tank with a float switch (or a float valve) to ensure that the water level in the header tank remains constant. A solar panel may provide the power for a pump to fill the header tank. Alternatively, the header tank may be filled using mains water pressure. Because the head of water at the control nozzle is constant, a pressure monitor tube is not required.

The irrigation may be operated manually as in Chapter 4 (Unpowered single-zone gravity feed measured irrigation). Alternatively, the irrigation may be automated as in Chapter 6 (Solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level).

7.2 Schematic diagram of solar-powered automated single-zone gravity feed measured irrigation with emitters at different levels



7.3 Measured Irrigation Nozzle Selector Tool for solar-powered automated single-zone gravity feed measured irrigation with emitters at different levels

For solar-powered automated single-zone gravity feed measured irrigation with emitters at different levels, the nozzle selector tool is the implementation of measured irrigation slope formula (3) and the nozzle formula. If you decide to use the Measured Irrigation Nozzle Selector Tool, it is preferable that the evaporator be exposed to full sun. Pictures of the *litres per week with BOM data* worksheet and the *litres per week without BOM data* are shown at the end of Section 4.4.

Using the nozzle selector tool for solar-powered automated single-zone gravity feed measured irrigation with emitters at different levels and with BOM data

1. Enter the control nozzle number into the relevant cell in the *litres per week with BOM data* worksheet. If you are using more than one nozzle for the control nozzle, adjust the relevant cell in the *litres per week with BOM data* worksheet. Enter the control volume into the relevant cell in the *litres per week with BOM data* worksheet. If you are using your own evaporator, you will need to measure the surface area of evaporation and adjust the relevant cell in the *litres per week with BOM data* worksheet. For each emitter nozzle, calculate the ratio of the head of water at the emitter nozzle to the head of water at the control and enter the result into the relevant cell in the *litres per week with BOM data* worksheet. Leave the other parameters at their default values.
2. Using the BOM (Bureau of Meteorology) evaporation data worksheet, find the BOM weather station nearest to your property (the weather stations are in alphabetical order). Copy and paste the mean monthly evaporation data January to December into the *litres per week* worksheet.
3. Go to the BOM website www.bom.gov.au/climate/data/index.shtml . Enter the location of your property and follow the prompts to find the weather station nearest to your property and then click *Get Data.* At the bottom of the data you there is the heading *Summary statistics for all years.* Copy and paste the mean monthly rainfall data January to December into the *litres per week* worksheet.
4. For each plant estimate the number of litres per week required during the hottest month of the year. Then use the *litres per week with BOM data* worksheet to select the corresponding emitter nozzle or nozzles. Note that measured irrigation does not help you decide how many litres per week a plant requires. However, once you have made a decision, the worksheet enables you to accurately implement your decision.
5. The *litres per week with BOM data* worksheet provides an estimate of the application rate in litres per week for each emitter nozzle for each month of the year. It also provides an estimate of the irrigation frequency (in waterings per week) for each month of the year, and an estimate of the irrigation volume for each emitter nozzle.

Using the nozzle selector tool for solar-powered automated single-zone gravity feed measured irrigation with emitters at different levels and without BOM data

1. Enter the control nozzle number into the relevant cell in the *litres per week without BOM data* worksheet. If you are using more than one nozzle for the control nozzle, adjust the relevant cell in the *litres per week without BOM data* worksheet. Enter the control volume into the relevant cell in the *litres per week without BOM data* worksheet. If you are using your own evaporator, you will need to measure the surface area of evaporation and adjust the relevant cell in the *litres per week without BOM data* worksheet. For each emitter nozzle, calculate the ratio of the head of water at the emitter nozzle to the head of water at the control and enter the result into the relevant cell in the *litres per week without BOM data* worksheet. Leave the other parameters at their default values.
2. Estimate of net evaporation in mm for the hottest month of the year and enter this value in the relevant cell in the *litres per week without BOM data* worksheet (measure the fall in the water level in a container with vertical sides exposed to full sun). Enter the number of days in the hottest month in the relevant cell in the *litres per week without BOM data* worksheet.
3. For each plant estimate the number of litres per week required during the hottest month of the year. Then use the *litres per week without BOM data* worksheet to select the corresponding emitter nozzle or nozzles. Note that measured irrigation does not help you decide how many litres per week a plant requires. However, once you have made a decision, the worksheet enables you to accurately implement your decision.
4. The *litres per week without BOM data* worksheet provides an estimate of the irrigation frequency (in waterings per week) for the hottest month of the year, and an estimate of the irrigation volume for each emitter.

If you are using dripline (either drip tube or drip tape) to irrigate your plants, the nozzle selector tool includes special worksheets for determining the number of drippers that each plant requires and the spacing required between the driplines to deliver the preferred litres per week per square metre. Pictures of the *dripline with BOM data* worksheet and the *dripline without BOM data* are shown below. When using these worksheets it is assumed that frictional head loss is negligible.

Dripline with BOM data worksheet (first page only)

Gravity feed measured irrigation on sloping ground using non pressure compensating dripline (drip tube or drip tape)

The number of drippers required in this worksheet is based on monthly evaporation and rainfall data.

surface area of evaporation in m^2	0.1090
spacing between drippers in metres	0.300
L/hr for control nozzle at 100 kPa	4.000
L/hr for dripper at 100 kPa	8.000
head of water in metres above control nozzle	1.500
preferred L/wk in hottest month for a particular plant	100
preferred L/wk/m^2 in hottest month	150

Note that the hottest month is the month that has the maximum nett evaporation (evaporation minus rainfall)

	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec	
copy and paste the average monthly evaporation in mm (in Australia use the BOM evaporation data worksheet)	284.7	239.8	203.2	130.9	82.4	57.7	61.1	85.2	120.6	175.0	220.3	257.1	Adelaide Airport
copy and paste the average monthly rainfall in mm	17.5	19.2	22.1	35	54.1	56.9	59.7	50.5	45.1	36.6	24.8	23.4	Adelaide Airport
nett evaporation in mm	267.2	220.6	181.1	95.9	28.3	0.8	1.4	34.7	75.5	138.4	195.5	233.7	

In Australia, monthly rainfall data is available from the Bureau of Meteorology website: http://www.bom.gov.au/climate/data/index.shtml

height in metres of control nozzle above dripper	number of drippers required for the particular plant in the hottest month	spacing in metres between driplines to deliver the preferred L/wk/m^2 in the hottest month
0.0	**7.6**	**0.292**
0.1	7.4	0.302
0.2	7.1	0.311
0.3	6.9	0.320
0.4	6.8	0.329
0.5	**6.6**	**0.338**
0.6	6.4	0.346
0.7	6.3	0.354
0.8	6.1	0.362
0.9	6.0	0.370
1.0	**5.9**	**0.377**

Dripline without BOM data worksheet (first page only)

Gravity feed measured irrigation on sloping ground using non pressure compensating dripline (drip tube or drip tape)

The number of drippers required in this worksheet is based on your estimate of the nett evaporation in the hottest month.

surface area of evaporation in m^2	0.1090
spacing between drippers in metres	0.300
L/hr for control nozzle at 100 kPa	4.000
L/hr for dripper at 100 kPa	8.000
head of water in metres above control nozzle	1.500
preferred L/wk in hottest month for a particular plant	100
preferred $L/wk/m^2$ in hottest month	150
estimate of nett evaporation in mm for hottest month	250
number of days in hottest month	31

Note that the hottest month is the month that has the maximum nett evaporation (evaporation minus rainfall)

height in metres of control nozzle above dripper	number of drippers required for the particular plant in the hottest month	spacing in metres between drip lines to deliver the preferred $L/wk/m^2$ in the hottest month
0.0	**8.1**	**0.273**
0.1	7.9	0.282
0.2	7.6	0.291
0.3	7.4	0.300
0.4	7.2	0.308
0.5	**7.0**	**0.316**
0.6	6.9	0.324
0.7	6.7	0.331
0.8	6.6	0.339
0.9	6.4	0.346
1.0	**6.3**	**0.353**
1.1	6.2	0.360
1.2	6.1	0.367
1.3	5.9	0.374
1.4	5.8	0.380
1.5	**5.7**	**0.387**
1.6	5.7	0.393
1.7	5.6	0.399
1.8	5.5	0.406
1.9	5.4	0.412
2.0	**5.3**	**0.418**
2.1	5.2	0.424
2.2	5.2	0.430
2.3	5.1	0.435
2.4	5.0	0.441
2.5	**5.0**	**0.447**

Chapter 8. Solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

8.1 Introduction to solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

This implementation of measured irrigation is suitable for much larger applications that require many separate irrigation zones or zones. In order to deliver water to all the zones simultaneously, you will need a **flow-splitter**.

The flow-splitter accurately divides a single inflow of water into multiple outflows with one outflow for each irrigation zone. The proportion of water delivered to each outlet is determined by the size of the flow-splitter nozzle attached to the outlet.

A control nozzle is connected to one of the outlets on the flow-splitter. In the pictures below the control nozzle is on the right. All the other nozzles are flow-splitter nozzles.

Flow-splitter variable nozzles and the control nozzle on the right

Flow-splitter mounted on star pickets

In the photo on the left a tube is connected to the control nozzle. This tube delivers water to the evaporator. The irrigation event will stop when the control volume of water has been delivered to the evaporator. The other tubes are delivering water to the various irrigation zones

The volume of water delivered to an irrigation zone during an irrigation event depends on the control volume and the ratio of the flow rate of the flow-splitter nozzle for the zone to the flow rate of the control nozzle. For example, if the control volume is 2 litres and the flow-splitter nozzle has 50 times the flow rate of the control nozzle, then 100 litres of water is delivered to the zone.

In the above photo the water level in the flow-splitter has stabilized so that the outflow rate matches the inflow rate. Suppose that the inflow is increased by adjusting the inlet valve. The water level in the flow-splitter will rise until the outflow rate matches the increased inflow rate. However, the volume of water delivered to the evaporator (namely, the control volume) does not change, and so the volume of water delivered to any zone does not change.

Note that a flow-splitter can be any shape or size provided that all the outlets on the flow-splitter are at the same level and hence the same pressure. The water supply for the flow-splitter may be from a solar-powered pump or from main water pressure.

8.2 Irrigation volumes for solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

In Section 6.4, the nozzle formula is used to predict the volume of water emitted by an emitter nozzle during the irrigation event for solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level. All the flow-splitter nozzles are at the same level, and hence the nozzle formula can also be used to predict the volume of water emitted by a flow-splitter nozzle during the irrigation event.

$$V = N_F * C \tag{4}$$

where

V is the volume of water emitted by one of the flow-splitter nozzle during the irrigation event,

N_F is the nozzle ratio of the flow-splitter nozzle to the control nozzle, and

C is the control volume.

Suppose that the flow-splitter nozzle is delivering water to emitter nozzles in the zone and the emitter nozzles are all at the same pressure. Then it can be shown that

$$V_E = N_F * C * N_E / S \tag{5}$$

where

V_E is the volume of water emitter by an emitter nozzle in the zone during the irrigation event,

N_E is the nozzle ratio of the emitter nozzle to the control nozzle, and

S is the sum of the nozzle ratios of all emitter nozzles in the zone.

Formula (5) is referred to as the **extended nozzle formula**. To predict the volume of water delivered by an emitter nozzle within a zone during the irrigation event, one can apply the extended nozzle formula.

If the flow-splitter nozzle is chosen so that the nozzle ratio of the flow-splitter nozzle is the same as the sum of the nozzle ratios for all the emitter nozzles in the zone, then the extended nozzle formula simplifies to become the nozzle formula

$$V_E = N_E * C$$

Furthermore, the pressure at the flow-splitter nozzle is the same as the pressure at the pressure at the emitter nozzles in the zone.

Irrigation frequency

For solar-powered automated multi-zone gravity feed measured irrigation, all zone are irrigated simultaneously and so the irrigation frequency is the same for all zones. There may be some zones that require a lower irrigation frequency that the frequency determined by the level sensor on the evaporator. This can be achieved for a particular zone by collecting all the water for the zone in a holding tank. When the water level in the tank reaches the prescribed level, all the water in the tank drains to irrigate the zone.

For example, if the nozzle formula (4) tells you that a particular zone will receive 100 litres of water during the irrigation event, then you can halve the irrigation frequency for the zone by using a holding tank that will hold 200 litres before the water is automatically flushed to the zone. Note that changing the irrigation frequency does not change the application rate (litres per week) for the zone.

Accuracy and Uniformity

Extensive research trials have demonstrated that the accuracy and uniformity of measured irrigation for a zone on level ground are both greater than 90%. The nozzles tested were the colour-coded needle nozzles in Table 1. This means that for the nozzles tested, the volume of water emitted from the nozzle during the irrigation event was within 10% of the predicted volume using the extended nozzle formula (4).

A research paper by Dr Bernie Omodei on the accuracy and uniformity of measured irrigation has been published in *Water Resources Management VII*, WIT Press 2013

A second research paper by Dr Bernie Omodei entitled "Accuracy and uniformity of a gravity feed method of irrigation" was published in January 2015 in the journal *Irrigation Science.*

Both papers are available from the measured irrigation website www.measuredirrigation.com.au

8.3 Application rates for solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

Measured irrigation level formula

The measured irrigation level formula (2) (see Section 4.3) can also be applied to the flow-splitter. Provided you have access to historical data for the mean monthly evaporation and the mean monthly rainfall in your locality, this information can be used to predict the application rate (litres per week) for each of the flow-nozzles in Table 1.

$$w_i = N_F * A * max(0, e_i - r_i) * 7 / n_i \qquad i = 1, 2, 3, \dots , 12$$

where

w_i is an estimate of the weekly application rate for the flow-splitter nozzle in month *i,*

N_F is the nozzle ratio of the flow-splitter nozzle to the control nozzle,

A is the surface area of evaporation,

e_i is the BOM mean monthly evaporation in month *i,*

r_i is the BOM mean monthly rainfall in month *i, and*

n_i is the number of days in month *i.*

Note that these estimates of the application rate for the flow-splitter nozzles depend only on the nozzle ratio, the surface area of evaporation, and BOM data. The estimates are independent of pressure, flow rate, irrigation frequency, and the duration of the irrigation event. Note that the estimate is zero whenever r_i is greater than e_i.

Extended measured irrigation level formula

The extended nozzle formula (5) in Section 8.2 can be used to derive the **extended measured irrigation level formula**

$$v_i = (N / S) * N_E * A * max(0, e_i - r_i) * 7 / n_i \qquad i = 1, 2, 3, \dots , 12 \qquad (6)$$

where

v_i is an estimate of the weekly application rate in month *i* for a particular emitter nozzle in a particular irrigation zone,

N_E is the nozzle ratio of the emitter nozzle to the control nozzle, and

S is the sum of the nozzle ratios of all the emitter nozzles in the zone.

By applying this formula to a particular emitter nozzle in a particular zone, one can decide whether the weekly application rate is too high or too low and make the appropriate adjustments.

Measured irrigation slope formula

The measured irrigation slope formula (3) derived in Section 7.1 can be used to estimate the weekly application rate for a particular emitter nozzle in a particular irrigation zone.

$$v_i = N_E * A * max(0, e_i - r_i) * 7 / n_i * (H_E / H_C)^x \qquad i = 1, 2, 3, \dots , 12 \qquad (7)$$

where

v_i is an estimate of the weekly application rate in month *i* for a particular emitter nozzle in a particular irrigation zone,

H_E is the head of water at the emitter nozzle,

H_C is the head of water at the control nozzle, and

x is the emitter discharge exponent.

The measured irrigation slope formula (7) can be used when *S* (the sum of the nozzle ratios for all of the emitter nozzles in the zone) is unknown.

The extended measured irrigation level formula (6) and the measured irrigation slope formula (7) provide equivalent estimates for the application rate for an emitter nozzle.

8.4 Measured Irrigation Nozzle Selector Tool for solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

For solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter, the nozzle selector tool is the implementation of the measured irrigation level formula (2), the extended measured irrigation level formula (6), the measured irrigation slope formula (7), the nozzle formula (4), and the extended nozzle formula (5). If you decide to use the Measured Irrigation Nozzle Selector Tool, it is preferable that the evaporator be exposed to full sun. Pictures of the *litres per week with BOM data* worksheet and the *litres per week without BOM data* are shown at the end of Section 4.4.

Using the nozzle selector tool for solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter with BOM data

1. Enter the control nozzle number into the relevant cell in the *litres per week with BOM data* worksheet. If you are using more than one nozzle for the control nozzle, adjust the relevant cell in the *litres per week with BOM data* worksheet. Enter the control volume into the relevant cell in the *litres per week with BOM data* worksheet. If you are using your own evaporator, you will need to measure the surface area of evaporation and adjust the relevant cell in the *litres per week with BOM data* worksheet.

2. Using the BOM (Bureau of Meteorology) evaporation data worksheet, find the BOM weather station nearest to your property (the weather stations are in alphabetical order). Copy and paste the mean monthly evaporation data January to December into the *litres per week* worksheet.

3. Go to the BOM website www.bom.gov.au/climate/data/index.shtml . Enter the location of your property and follow the prompts to find the weather station nearest to your property and then click *Get Data.* At the bottom of the data you there is the heading *Summary statistics for all years.* Copy and paste the mean monthly rainfall data January to December into the *litres per week* worksheet.

4E. **Emitter nozzle.** For each plant estimate the number of litres per week required during the hottest month of the year. Then use the *litres per week with BOM data* worksheet to select the corresponding emitter nozzle or nozzles. After installing the emitter nozzles for each zone, adjust the valve flow-splitter nozzle until the head of water in the flow-splitter matches the head of water in the pressure monitor tube for the zone. If the pressure in the flow-splitter is not the same as the pressure in the zone, the estimates of the irrigation volumes and application rates for the emitter nozzles in the zone will not be correct. To correct the estimates, measure the ratio of the head of water in the flow-splitter to the head of water in the pressure monitor tube for the zone, and enter this value in the relevant cell in the worksheet.

or 4F. **Flow-splitter nozzle.** For each zone estimate the number of litres per week required during the hottest month of the year. Then use the *litres per week with BOM data* worksheet to select the corresponding flow-splitter nozzle or nozzles. After installing the emitter nozzles for the zone, check that the emitter nozzle correction factor is set to its default value of 1 and then use the **irrigation volume in litres** column in the *litres per week with BOM data* worksheet to calculate the emitter nozzle correction factor which is the ratio of (the volume of water emitted by the flow-splitter nozzle) to (the total volume of water emitted by all the emitter nozzles in the zone). Enter the emitter nozzle correction factor into the relevant cell in the worksheet to obtain the correct irrigation volumes and application rates for the emitter nozzles in the zone.

5. The *litres per week with BOM data* worksheet provides an estimate of the application rate in litres per week for each emitter nozzle for each month of the year. It also provides an estimate of the irrigation frequency (in waterings per week) for each month of the year, and an estimate of the irrigation volume for each emitter nozzle.

Using the nozzle selector tool for solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter without BOM data

1. Enter the control nozzle number into the relevant cell in the *litres per week without BOM data* worksheet. If you are using more than one nozzle for the control nozzle, adjust the relevant cell in the *litres per week without BOM data* worksheet. Enter the control volume into the relevant cell in the *litres per week without BOM data* worksheet. If you are using your own evaporator, you will need to measure the surface area of evaporation and adjust the relevant cell in the *litres per week without BOM data* worksheet.

2. Estimate of net evaporation in mm for the hottest month of the year and enter this value in the relevant cell in the *litres per week without BOM data* worksheet (measure the fall in the water level in a container with vertical sides exposed to full sun). Enter the number of days in the hottest month in the relevant cell in the *litres per week without BOM data* worksheet.

3E. **Emitter nozzle.** For each plant estimate the number of litres per week required during the hottest month of the year. Then use the *litres per week without BOM data* worksheet to select the corresponding emitter nozzle or nozzles. After installing the emitter nozzles for each zone, adjust the valve flow-splitter nozzle until the head of water in the flow-splitter matches the head of water in the pressure monitor tube for the zone. If the pressure in the flow-splitter is not the same as the pressure in the zone, the estimates of the irrigation volumes and application rates for the emitter nozzles in the zone will not be correct. To correct the estimates, measure the ratio of the head of water in the flow-splitter to the head of water in the pressure monitor tube for the zone, and enter this value in the relevant cell in the worksheet.

or 3F. **Flow-splitter nozzle.** For each zone estimate the number of litres per week required during the hottest month of the year. Then use the *litres per week with BOM data* worksheet to select the corresponding flow-splitter nozzle or nozzles. After installing the emitter nozzles for the zone, check that the emitter nozzle correction factor is set to its default value of 1 and then use the **irrigation volume in litres** column in the *litres per week with BOM data* worksheet to calculate the emitter nozzle correction factor which is the ratio of (the volume of water emitted by the flow-splitter nozzle) to (the total volume of water emitted by all the emitter nozzles in the zone). Enter the emitter nozzle correction factor into the relevant cell in the worksheet to obtain the correct irrigation volumes and application rates for the emitter nozzles in the zone.

4. The *litres per week without BOM data* worksheet provides an estimate of the irrigation frequency (in waterings per week) for the hottest month of the year, and an estimate of the irrigation volume for each emitter.

If you are using dripline (either drip tube or drip tape) to irrigate your plants, the nozzle selector tool includes special worksheets for determining the number of drippers that each plant requires and the spacing required between the driplines to deliver the preferred litres per week per square metre. Pictures of the *dripline with BOM data* worksheet and the *dripline without BOM data* are shown at the end of Section 7.3. When using these worksheets it is assumed that frictional head loss is negligible

8.5 Installing solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

It is recommended that you watch the YouTube video entitled *Measured Irrigation – step by step instructions* www.youtube.com/watch?v=4A2I-U2HG4g

Step 1. Position two star pickets so that the support for the flow-splitter fits neatly between them with the holes in the star pickets facing the flow-splitter. Use nylon fishing line to support the flow-splitter. Use a spirit level to ensure that the flow-splitter is horizontal. The flow-splitter should be at least one metre higher than all the irrigation zones. If some of the zones are a long distance from the flow-splitter, then the flow-splitter should be sufficiently high to allow for the frictional head loss between the flow-splitter and the distant zones.

Step 2. Connect the outlet valve on the water tank to the flow-splitter via the filter, the pump, the inlet valve and the solenoid valve.

Step 3. Connect the valve controller to the pump, the solenoid valve and the level sensor. Connect a 12 volt power supply to the valve controller. See Notes 2 and 3 for details.

> Step 2 using mains water. Connect the mains water supply to the flow-splitter via the filter, the inlet valve and the solenoid valve.
>
> Step 3 using mains water. Connect the valve controller to the solenoid valve and the level sensor. Connect a 12 volt power supply to the valve controller. See Note 2 for details.

Step 4. Position the evaporator so that it is exposed to full sun. Position the level sensor on the evaporator. It is recommended that you secure the level sensor to the evaporator (using cable ties for example) to prevent the level sensor accidentally falling into the water.

Step 5. The Measured Irrigation Nozzle Selector Tool will help you to select the control nozzle. Attach the control nozzle to an outlet on the flow-splitter and use a length of 6 mm flexible tube to connect the control nozzle to the evaporator. Ensure that the control nozzle outlet is open to the atmosphere.

Step 6. The control volume is the volume of water that is delivered to the evaporator during the irrigation event. It is also the volume of water that must be removed from the evaporator so that the water level falls from the high level at the end of the irrigation event to the low level (low probe). See Note 4 for more details on how to measure the control volume.

Step 7. The irrigation down time is the time it takes for the water level in the evaporator to fall (due to evaporation) from the high level at the end of the irrigation event to the low level (low probe). One can increase or decrease the irrigation down time by increasing or decreasing the number of millimetres between the high probe and the low probe (the probe lengths are adjustable). The Measured Irrigation Nozzle Selector Tool will help you to choose a control volume that will generate an appropriate irrigation frequency for your garden.

Step 8. For each zone, connect a network of polypipe from the flow-splitter so that all the plants to be watered are close to the nearest polypipe. Do not use hose clamps, they are not needed. To minimise head loss, 19 mm polypipe is recommended. As the distance from the water tank to the zone increases, you may need to increase the diameter of the polypipe to compensate for head loss.

Step 9. For each plant in each zone, punch a hole in the nearest polypipe and insert a take-off adaptor into the hole. Cut a suitable length of 6 mm flexible tube to deliver water to the plant. Attach one end of the tube to the take-off adaptor and the other end to an emitter nozzle or a length of Miniscape or Bioline drip tube. Don’t worry if you don’t know what nozzle to use - you can change a nozzle at any time if a plant is getting too much or too little water. The Measured Irrigation Nozzle Selector Tool will help you to select a suitable emitter nozzle. If you are using drip tube it may be connected directly to the polypipe without using flexible tube.

Step 10. For each zone, connect a pressure monitor tube to the polypipe. A pressure monitor tube is used to check the pressure at any point in the zone to be confident that everything is working according to your expectations.

Step 11. For each zone, connect an adjustable valve nozzle (N18 or N19) to a flow-splitter outlet. Adjust the inlet valve until the water level in the flow-splitter stabilises at the desired level. Adjust the valve on the flow-splitter nozzle until the head of water in the flow-splitter is the same as the head of water in the pressure monitor tube. The head of water in the flow splitter is measured from the control nozzle outlet. Note that all nozzles should be open to the atmosphere.

Step 12. For normal operation (assuming a solar panel is used) the switch on the valve controller should be set to **night only ON** so that irrigation starts after sunset. Set the switch to **battery ON** for testing or demonstration purposes or when the garden urgently needs to be watered. To start the irrigation manually simply raise one side of the level sensor so that the low probe is out of the water. If you decide that you garden needs an extra watering, then remove some water from the evaporator to start watering.

Zone on level ground

To ensure that the pressure is the same at all emitter nozzles in the zone, the nozzles should be at the same level and you need to minimise any head loss between the nozzles. You can use pressure monitor tubes to check the pressure at any emitter nozzle and if variations in pressure are unacceptable you can either adjust the levels of the nozzles or increase the diameter of the polypipe.

Zone on sloping ground

Position a length of polypipe so that it follows a contour line higher than all the plants in the zone to be watered by emitter nozzles attached to the length of polypipe. A length of 6 mm tube delivers the water from the nozzle to the plant at a lower level. Note that there is a small breather hole in the black tube protecting the nozzle to ensure that the nozzle remains at atmospheric pressure.

Note 1

If water is overflowing at a flow-splitter nozzle attached to the flow-splitter, there may be pockets of air trapped at high points in the polypipe. If you can't remedy the situation by physically removing the high points, you may need to insert an air valve at one or more of the high points. To insert an air valve, simply cut the poylpipe at the high point and insert a tee and a vertical piece of poylpipe higher than the outlet on the flow-splitter.

If there is still a problem after you have attempted to remove trapped air, you can either

- Use polypipe of greater diameter (for example, change from 13 mm polypipe to 19 mm polypipe) or
- Raise the level of the flow-splitter

Note 2

There are 7 colour coded leads coming from the valve controller. The leads should be connected as follows:
blue lead connects to the positive lead from the power supply (not solar panel)
green lead connects to the negative lead from the power supply (not solar panel)
white lead connects to the white lead from the level sensor (reference probe)
pink lead connects to the red (or yellow) lead from the level sensor (high probe)
brown lead connects to the black lead from the level sensor (low probe)
grey lead connects to the black lead from the pump (or solenoid valve)
yellow lead connects to the red lead from the pump (or solenoid valve).

If you ever need to replace the circuit board inside the valve controller, follow the following instructions:
Connect the **Lo** terminal on the board to the brown lead.
Connect the **Ref** terminal on the board to the white lead.
Connect the **Hi** terminal on the board to the pink lead.
Connect the **Bat +** terminal on the board and the yellow lead to the middle negative spade of the switch.
Connect the **Bat -** terminal and the **Com** terminal on the board to the middle positive spade of the switch.
Connect the **NO** terminal on the board to the grey lead.

Note 3

A 20 watt solar panel provides enough power to automatically irrigate 200 m^2 at 10 litres per m^2 using a 14 watt pump connected to a water tank at ground level.
A 40 watt solar panel provides enough power to automatically irrigate 400 m^2 at 10 litres per m^2 using two 14 watt pumps connected to a water tank at ground level.
A 60 watt solar panel provides enough power to automatically irrigate 600 m^2 at 10 litres per m^2 using three 14 watt pumps connected to a water tank at ground level.
An 80 watt solar panel provides enough power to automatically irrigate 800 m^2 at 10 litres per m^2 using four 14 watt pumps connected to a water tank at ground level.

Note 4

In order for measured irrigation to accurately predict the volume of water delivered to each zone and the volume of water delivered to each plant within each zone, you need to accurately measure the control volume. The following method is recommended. At the end of the irrigation event slowly take water from the evaporator and transfer it to another container. As the water level gets close to the low level, carefully remove the water with a syringe until the water level separates from the low probe and the valve controller starts the next irrigation event. The volume of water in the container is the control volume.

Note 5

If you decide that for all zones your plants are getting too much water during the irrigation event, either increase the size of the control nozzle or decrease the surface area of evaporation (see Chapter 11). On the other hand, if you decide that for all zones your plants are not getting enough water, either decrease the size of the control nozzle or increase the surface area of evaporation.

Note 6

You may wish to cover the flow-splitter with a light-proof cover to prevent the formation of algae.

Note 7

If the power supply is from a solar panel, you may wish to replace the level sensor and the valve controller by a float switch and power relay as described in Section 6.8. The irrigation will start automatically at sunset provided that the float switch is on. The irrigation will stop when the water level has risen and turned off the float switch (or the sun rises).

8.6 Solar-powered automated multi-zone gravity feed measured irrigation kit with flow-splitter

The kit consists of the following components and may be purchased from the measured irrigation website.

Measured Irrigation Manual	1
solenoid valve 12V 5W	1
valve controller	1
charge controller with night load option	1
waterproof control box	1
level sensor with 3 probes	1
evaporator	1
filter – 120 mesh	1
inlet valve	1
pump 12V 14W	1
flow-splitter nozzles (one of each type)	20
extra 9mm valve nozzles	4
Netafim Miniscape drip tube with 0.15m dripper spacing (metres)	4
Netafim Bioline drip tube with 0.3m dripper spacing (metres)	4
flow-splitter with inlet valve and 25 outlets	1
pressure monitor tubes	4
electrical irrigation cable - 3 strand (metres)	10
electrical irrigation cable connectors	7
light-proof cover for flow-splitter	1

The kit does not include the solar panel and the battery

Pump 12V 14W

Evaporator and level sensor with 3 probes

Light-proof cover protecting the flow-splitter

Chapter 9. Solar-powered automated multi-zone gravity feed measured irrigation without flow-splitter

This implementation of measured irrigation is a simple extension on the single-zone implementation in Section 6.8. For each additional zone you will need an evaporator, a solenoid valve, a float switch, and a power relay.

Depending on the number of zones, you may need to use a 20 watt solar panel instead of a 10 watt solar panel.

Because the irrigation is gravity feed, the number of zones required is likely to increase significantly on sloping ground and hence it may be preferable to use a flow-splitter.

A major advantage of using a separate evaporator for each zone is that application rate for each zone can be adjusted by adjusting the surface area of evaporation from the evaporator (see Chapter 11).

Chapter 10. Other measured irrigation applications

The principles of measured irrigation are completely scalable to larger or smaller irrigation systems.

For large irrigation systems you may use many flow-splitters in a hierarchical configuration. Each flow-splitter can be as large or as small as required and each flow-splitter can have as many outlets as required. Each outlet on the top level flow-splitter may deliver water to a second level flow-splitter. The choice of power supply and the choice of pump depend on the number of litres per hour required by the top level flow-splitter. For large irrigation systems pipes of greater diameter are required to manage head loss. For larger scale irrigation applications it is preferable to use a pressurised water supply to the flow-splitter. Measured irrigation with a flow-splitter needs to be gravity feed only after the water enters the flow-splitter.

An example of a small irrigation system is one to water all your indoor plants when you go on holidays.

Measured irrigation can also be used to control the delivery of drinking water to animals.

Measured irrigation of seedlings in a commercial nursery

Measured irrigation can provide an extremely water-efficient method or watering thousands of seedlings in commercial nurseries. By using a moving boom above the seedlings, and arranging the seedlings in rows so that all seedlings in the same row require the same amount of water, all seedling can receive the amount of water required. The savings in water bills will be significant compared with overhead spray irrigation

The photo on the left is a prototype of measured irrigation on a boom at Provenance Indigenous Plants in Adelaide.

More details are available on the YouTube video entitled *Measured irrigation for seedlings in nurseries*

https://www.youtube.com/watch?v=qNd6TkL9yzI

Upgrading clay pot or pitcher irrigation to measured irrigation

The use of buried unglazed clay pots, often called ‘pitcher irrigation’, is a very ancient irrigation technology appropriate for home gardens, especially in dry areas in developing countries. The pot is buried near the root zone of trees (or other crops), filled with water, and covered to prevent evaporation. The water seeps slowly through the porous sides of the pot. Measured irrigation can be used to control the delivery of water to the clay pots.

Chapter 11. How to adjust the surface area of evaporation

The amount of water that your plants need will depend on many factors in addition to the weather. For example, as the plants grow and become bigger they will need more water. Plants growing in sandy soil will need more water than plants growing in heavy soil.

To take account of all these additional factors, I recommend that you use a length of steel pipe to check the moisture level in the soil. I suggest that the diameter of the pipe be between 40 and 50 mm. An angle grinder can be used to cut some slots in the steel pipe to that you can inspect the soil inside the pipe. I suggest that the width of the slots be about 13 mm.

An angle grinder is used to cut some slots in a length of steel pipe

Early in the morning after irrigation the night before, push (or hammer) the steel pipe into the soil near a dripper.

Remove the steel pipe from the soil and use the slots to inspect the moisture level in the soil and the position of the wetting front.

By checking the moisture level in the soil through the slots in the steel pipe, you can decide whether the plants have been irrigated the night before with too much or too little water. If the plants have been given too much water then you can reduce the water usage by reducing the surface area of evaporation from the evaporator. For example, the surface area of evaporation can be reduced by placing full bottles of water in the evaporator. On the other hand, if the plants have not been given enough water then you will need to increase the surface area of evaporation. After irrigation and adjustments over several days, the surface area of evaporation should stabilise at an appropriate level for the plants at their current stage of growth.

As your plants grows and the water requirement of the plants changes, you may wish to repeat the process of adjusting the surface area of evaporation.

In this case 2 large drinking bottles have been used to adjust the surface area of evaporation.

Chapter 12. Low cost measured irrigation in developing countries

12.1 Introduction to low cost measured irrigation in developing countries

Drip irrigation has become synonymous with modern and efficient irrigation practices that conserve precious water resources and maximise plant performance. However the biggest barrier to the adoption of drip irrigation in developing countries has been the installation cost.

The two most popular technologies for low cost micro irrigation are gravity feed drip tube (or drip tape) irrigation and gravity feed micro tube irrigation. A low cost system needs to be gravity feed to avoid the additional cost of buying, running and maintaining a pump.

Both technologies have the following disadvantages which can be addressed by upgrading to unpowered gravity feed measured irrigation.

- When the land is uneven or sloping, errors will occur in the calculation of the volume of water delivered to each plant. Netafim recommends that the slope of the land should be less than 2%.
- Neither technology adjusts the application rate to the plants according to the prevailing weather conditions. Poor water efficiency is likely to occur because of poor decisions made by the smallholder in relation to variations in the application rate. With measured irrigation the application rate for each plant is automatically adjusted to take account of the prevailing weather conditions.

It is appropriate to regard gravity feed measured irrigation as an extension or refinement of low cost gravity feed drip irrigation.

Measured irrigation is a simple and appropriate technology for smallholders because the drip irrigation system can be upgraded to measured irrigation using local resources and materials at almost no cost. On sloping or uneven ground, unpowered multi-zone gravity feed measured irrigation is recommended (see Chapter 5).

12.2 How to upgrade unpowered drip irrigation to measured irrigation

It is recommended that you watch the YouTube video entitled *Upgrade gravity feed drip irrigation to measured irrigation*

https://www.youtube.com/watch?v=IClFyWiCpWc

Many smallholders in developing countries have installed low cost drip irrigation kits purchased from the non-profit development organisation IDE (International Development Enterprises). For some IDE kits a dripper is a short length of microtube.

Measured irrigation upgrade instructions for level ground

Additional materials required: bucket (or container)

Step 1 Select a suitable evaporator with vertical sides. If all the drippers in the zone are the same, then the volume of water emitted by each dripper during the irrigation event is the same as the net volume of water that has evaporated from the evaporator since the previous irrigation.

Step 2 Mark a level line on the inside of the evaporator about 3 cm below the overflow level.

Step 3 Position the evaporator in a suitable location so that a single dripper drips water into the evaporator during the irrigation event. This dripper is called the control nozzle and it should be at the same level as all the other drippers.

Step 4 Fill the evaporator with water so that the water level is about 1 cm below the level line.

Step 5 Open the valve to commence irrigation. Close the valve when the water level reaches the level line.

Step 6 The water level in the evaporator falls due to evaporation. Open the valve when the water level is below the level line and the next watering is required. The cycle continues indefinitely.

Step 7 The application rate can be adjusted by adjusting the surface area of evaporation from the evaporator (see Chapter 11).

Measured irrigation upgrade instructions for sloping or uneven ground

Additional materials required: buckets and valves

Step 1 Group the plants to be irrigated into zones so that the plants in each zone are at approximately the same level. Each zone needs its own evaporator and valve.

Step 2 For each zone select a suitable evaporator with vertical sides. If all the drippers in the zone are the same, then the volume of water emitted by each dripper during the irrigation event is the same as the net volume of water that has evaporated from the evaporator since the previous irrigation.

Step 3 Mark a level line on the inside of each evaporator about 3 cm below the overflow level.

Step 4 For each zone, position an evaporator in a suitable location so that a single dripper drips water into the evaporator during the irrigation event. This dripper is called the control nozzle for the zone and it should be at the same level as all the other drippers in the zone.

Step 5 Fill the evaporators with water so that the water level is about 1 cm below the level line.

Step 6 Open the valves to commence irrigation. Close the valve for each zone when the water level reaches the level line.

Step 7 The water level in each evaporator falls due to evaporation. For each zone, open the valve when the water level has fallen below the level line and the next watering is required. The cycle continues indefinitely.

Step 10 For each zone, the application rate can be adjusted by adjusting the surface area of evaporation from the evaporator for the zone (see Chapter 11).

Six reasons to upgrade drip irrigation to measured irrigation

1. Save more water by controlling the application rate by adjusting the surface area of evaporation from the evaporator.
2. Save more water by allowing the prevailing weather conditions to control the variations in the application rate for each dripper throughout the year. When the temperature increases, the application rate increases. When it rains, the application rate decreases. The application rate for each dripper is directly proportional to the current net evaporation rate (evaporation minus rainfall).
3. Save more water by maintaining the same level over control of the application rate for each dripper on sloping ground by using multiple zones.
4. The smallholder can control the irrigation frequency for each zone. If a zone requires more frequent irrigation with less water, then the smallholder should open the valve for the zone when the water level is less than 1 cm below the level line. If a zone requires less frequent irrigation with more water, then the smallholder should open the valve for the zone when the water level is more than 1 cm below the level line
5. Because irrigation is more water-efficient after the upgrade, additional water is available to extend your garden and to irrigate more plants.
6. The cost of the upgrade on level ground is the cost of a bucket.

12.3 DIY (Do It Yourself) solar drip irrigation

Detailed guidelines are available for smallholders who are using a farm pond for gravity feed drip irrigation on a small plot of land. The title of the document is “DIY solar drip irrigation” and it can be downloaded from the measured irrigation website
www.measuredirrigation.com.au

It is recommended that you watch the YouTube video entitled *DIY solar drip irrigation*
https://www.youtube.com/watch?v=wR9PAgawjLU

I will assume that water needs to be pumped from a farm pond up to a raised header tank and that the depth of the farm pond is no more than 4 metres.

By reading these guidelines, a farmer is taking the first step towards automating their drip irrigation system so that he or she can leave their plot unattended for weeks. At sunset each evening, water will be automatically pumped from the farm pond to the header tank, and all the plants will be automatically irrigated by measured irrigation. This will allow the farmer to spend more time generating income from other activities away from the farm; for example, travelling to the market to sell their produce.

Do It Yourself solar drip irrigation requires the farmer to solve any problems that may arise and to break the cycle of dependency upon the so-called experts. By following these guidelines the farmer will learn new skills. When the automation of the drip irrigation system is complete, the farmer will then become the expert, and their knowledge and expertise can be shared with other farmers. I am assuming that the farmer has access to the Internet and to Google. Google will help you find solutions to problems and low cost components from anywhere in the world, especially China.

The total cost of automating the drip irrigation system will be less than $200. However, the cost may be much less if the farmer is able to develop low cost solutions to various challenges that may arise during the Do It Yourself implementation.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Farm pond in Kenya for gravity feed drip irrigation

Chapter 12. Sophie's Patch

Sophie's Patch uses solar-powered automated multi-zone gravity feed measured irrigation with a flow-splitter.

Sophie's Patch is a beautiful demonstration garden near Mount Barker in the Adelaide Hills. The garden has been designed by Sophie Thompson, the South Australian presenter for Gardening Australia on ABC TV. The garden is often featured in Gardening Australia programs. The garden includes a large vegetable growing area and prior to the installation of measured irrigation the garden was watered by overhead spray. Every plant in the vegetable garden is now irrigated by measured irrigation and so every plant receives the desired application rate throughout the year, automatically responding to changes in the weather conditions.

Because the vegetable garden is on sloping land, it was decided to use 11 irrigation zones and each zone follows a contour. The water supply is from a bore and the water has a high salt content of approximately 2000 parts per million.

An important step in designing the irrigation system is to decide the application rate for each plant in the garden for the hottest month of the year and to use the Measured Irrigation Nozzle Selector Tool to select the appropriate nozzle or nozzles. More than half the vegetable garden has rows of low growing vegetables and it was decided to apply 130 litres per square metre per week during the month of January. This application rate in January is achieved with Netafim Miniscape drip tube with 15 cm spacing between the drippers and 25 cm spacing between the rows of dripperline. Most of the tomato plants are watered with yellow nozzles delivering 16 litres per week in January and the pumpkin plants are watered with brown nozzles delivering 27 litres per week in January. Note that the control nozzle consists of a single Miniscape dripper. The predicted application rates in the Measured Irrigation Nozzle Selector Tool are based on the Bureau of Meteorology average monthly evaporation and rainfall for Mount Barker.

Bernie Omodei & Sophie Thomson celebrate the successful installation of measured irrigation at Sophie's Patch at Mount Barker

Evaporator and level sensor

Sophie’s son Beau adjusts the angle of the 20 watt solar panel

Flow-splitter measuring the water delivered to each of the eleven irrigation zones

You can see from this picture how the land slopes down towards the old railway carriage. Measured irrigation manages the slope by making the zones follow the contours.

Zone 4 is irrigated by 5 rows of Miniscape drip tube 25cm apart and the drippers are 15 cm apart. This arrangement delivers130 litres per square metre per week during January.

Each zone has a clear pressure monitor tube indicating the water pressure in the zone. Beau is pointing to the water level in zone 11 and the pressure is about 40 cm head of water.

Chapter 13. Community Gardens

13.1 Camden CG – solar-powered automated single-zone gravity feed measured irrigation

This community garden in Adelaide has 9 raised beds. Because all the beds are at the same level, solar-powered automated single-zone gravity feed measured irrigation with emitters at the same level was the preferred implementation. All beds are irrigated with Netafim Miniscape drip tube with 15 cm spacing between the drippers. It was decided that a suitable application rate for all beds in January (the hottest month of the year) should be 2.2 litres per dripper per week. This application rate is generated by a green hobby box as the evaporator and with 3 Miniscape drippers dripping into the evaporator.

All 9 beds use Miniscape drip tube

The pressure monitor tube shows a pressure of about a metre head of water

13.2 Henley CG – solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

Henley Community Garden is an organic permaculture designed community garden created by local resident volunteers in 2013 on land administered by the City of Charles Sturt in Adelaide. Every plant in the garden (excluding the wicking beds) is irrigated by measured irrigation and so every plant receives the desired a. This demonstration site has 12 Miniscape drip tube zones. The control volume is 1.0 litres and the control nozzle is yellow. This site is quite large and requires more than 1500 litres per hour to irrigate the whole garden. Furthermore, the site does not have access to mains power or to mains water and so pressurised drip irrigation is not an option. All the power required is provided by four 20 watt solar panels which power four 14 watt pumps delivering more than 1500 litres per hour to the flow-splitter. The water supply is bore water stored in two large tanks.

Miniscape drip tube zone

Miniscape drip tube zone

13.3 Prospect CG – solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

It is recommended that you watch the YouTube video entitled *Measured irrigation without mains power or water:* https://www.youtube.com/watch?v=dvCZZAp3QTU

The Prospect Community Garden was constructed in 2011 on a 1500 square metre block of land owned by the City of Prospect in Adelaide. Every plant in the garden is irrigated by measured irrigation and receives the desired amount of water during the irrigation event. This demonstration site has 13 gravity feed porous hose zones. The control volume is 1.7 litres and the control nozzle is green. For each zone, the water requirement per irrigation and the corresponding flow-splitter nozzle are listed in the table below.

zone	zone description	water requirement	nozzle
0	9 metres of porous hose, high level garden bed	110 L	large rivet
1	10 metres of porous hose, high level garden bed	110 L	large rivet
2	9 metres of porous hose, low level garden bed	110 L	large rivet
3	10 metres of porous hose, low level garden bed	110 L	large rivet
4	9.5 metres porous hose, low level garden bed	110 L	large rivet
5	10 metres of porous hose, two low level garden beds	110 L	large rivet
6	7.5 metres of porous hose, high plastic garden bed	80 L	medium rivet
7	3 metres of porous hose, high plastic garden bed	30 L	olive
8	7.5 metres of porous hose, high plastic garden bed	80 L	medium rivet
9	6 metres of porous hose, 6 large barrel pots	50 L	small rivet
10	18 metres of porous hose, herb garden beside tanks	200 L	5/32 inch washer
11	32 metres of porous hose, fruit trees and vines beside southern fence	350 L	5 mm washer
12	60 metres of porous hose, fruit trees and vines beside western and northern fences, and nearby garden beds	700 L	2 x 5 mm washer
	Total water requirement	**2150 L**	

Volunteers installing gravity feed porous hose

Volunteers planting tomatoes

13.4 Glenelg North CG – solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

This site was initially set-up to use 11 of the 25 outlets on the flow-splitter. There are 9 gravity feed porous hose zones and one emitter nozzle zone. The control volume is 1.15 litres and the control nozzle is brown. The site is on land owned by the City of Holdfast Bay in Adelaide.

Michael Dwyer attending the flow-splitter

Loops of gravity feed porous hose irrigate the fruit trees

Measured irrigation in raised garden beds

13.5 Yarrawonga CG – solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

This site was established by volunteers in the country town of Yarrawonga in Victoria.

Newly constructed raised garden beds

Tom Hutchinson installing measured irrigation

13.6 Fern Avenue Community Garden

This demonstration site is about 2200 square metres of land owned by the City of Unley in Adelaide. The irrigation system uses 7 of the 25 outlets on the flow-splitter. There are 2 gravity feed porous hose zones, 2 Miniscape drip tube zones and 2 emitter nozzle zones. Measured irrigation was installed at Fern Avenue Community Garden in August 2011 and it was the first measured irrigation installation anywhere in the world.

Chapter 14. Private Gardens

1

4.1 Cambridge Street Garden (Vale Park, Adelaide) – solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

This large garden has 9 zones and the water comes from a 22,000 litre rainwater tank. The water tank is at the lowest point on the property and four 14 watt pumps are required to pump the water uphill to the flow-splitter 75 metres away.

Four 20 watt solar panels provide the power

A banana tree receives 50 L/week in January from a loop of Netafim Bioline, plus an additional 36 L/week in January from a white needle nozzle (nozzle 7)

Four 14 watt pumps provide sufficient flow to the flow-splitter 75 metres away and about 4 metres higher

This zone has 4 fruit trees beside a fish pond, and each tree receives 50 L/week in January plus extra from a needle nozzle

A light-proof cover protects the flow-splitter from algae formation

This zone is a long narrow bed with 3 rows of Miniscape

A citrus tree receives 50 L/week in January from a loop of Bioline, plus an additional 23 L/week in January from a pink needle nozzle (nozzle 6)

14.2 Bushman Drive Garden (Walkley Heights, Adelaide) – solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

All the plants in this large private garden are watered automatically. There are 8 zones using a combination Netafim Miniscape drip tube with 15 cm spacing between the drippers and Measured Irrigation needle nozzles. The water supply is from the mains.

A light-proof cover for the flow-splitter prevents the formation of algae

A loop of Miniscape drip tube delivers 30 litres per week in January to a rose bush

A white needle nozzle (nozzle 7) delivers 35 litres per week in January to a nearby plant at a lower level.

14.3 Bremer Bay Garden (Western Australia) – solar-powered automated multi-zone gravity feed measured irrigation

14.4 Thorngate Drive Garden (Belair, Adelaide) – solar-powered automated multi-zone gravity feed measured irrigation with flow-splitter

All the plants in this very large private garden are watered automatically. Because the block of land slopes steeply from the back yard to the front yard, 11 zones are needed, each zone following a particular contour. The garden uses a combination Netafim Miniscape drip tube with 15 cm spacing between the drippers, and Netafim Bioline with 30 cm spacing between the drippers.

Flow-splitter supplying water to 11 zones. Each outlet valve is adjusted so that the head in the pressure monitor tube for the zone matches the head in the flow-splitter.

Zone beside the driveway using Miniscape drip tube

Each level is a separate zone

14.5 Harvey Street Garden (Woodville Park, Adelaide) – pot plant zone

Gravity feed porous hose is ideal for bottom-watering of pot plants. A loop of porous hose is inserted in the bottom of the pot before filling with soil. The zone uses unpowered single-zone gravity feed measured irrigation.

Loop of gravity feed porous hose at the bottom of each pot

Polypipe is connected to a loop of gravity feed porous hose at the bottom of the pot

Chapter15. Measured irrigation demonstration sites and contacts

South Australia

Sophie's Patch, phone Sophie Thomson on 0415 841619
Prospect Community Garden, phone Alan on 0429 970466
Camden Community Garden, phone Ken on 0439 800882
Fern Avenue Community Garden (Fullarton), phone John on 0487 172475
Henley Community Garden, phone John on (08) 82359926
Glenelg North Community Garden, phone Michael on (08) 82940709
Trott Park Community Garden, phone Malcolm on 0431 615114
Windsor Gardens Vocational College, phone Peter on 0401 121368
Harvey Street Garden (Woodville Park), phone Bernie on 0403 935277
Colac Street Garden (Greenacres), phone Katie on 0411 312532
Skipper Street Garden (Mount Barker), phone Gunther on 0432 877105
Radstock Street Garden (Woodville Park) phone Bernie on 0403 935277
Bushman Drive Garden (Walkley Heights), phone Grace on (08) 83596495
Argyle Tce Garden (Klemzig), phone Dan on 0437 480745
Cambridge Street Garden (Vale Park), phone Nathan on 0414 902348
Thorngate Drive Garden (Belair), phone Les and Teresa on 0401 125999

Victoria

Yarrawonga Community Garden, phone Tom on 0438 589149
Allens Road Community Herb Garden (Heathmont), phone Will on 0432 747270

ACT

Community Garden, phone Adrian on 0449 837211

Queensland

University of Sunshine Coast Community Garden (Maroochydore), phone Helen on 0401 839506

WA

Property at Bremer Bay, phone Rod on 0429 988733

Appendix 1. Emitter flow equation

Measured irrigation principle

With measured irrigation the plants to be irrigated are often grouped into zones (zones) whereby the irrigation of each zone is independent of all the others zones. For each zone, the emitters should satisfy the measured irrigation principle which is defined as follows:

> *For any two emitters in a zone and at the same pressure, the ratio of the flow rates is independent of the pressure within the operational pressure range for the zone.*

To ensure that the measured irrigation principle is satisfied for a particular irrigation application, it is important to introduce the emitter flow equation.

Emitter flow equation

Micro-irrigation emitter flow rates have different responses to pressure variations. The response of a specific emitter depends on its design and construction. The relationship between emitter operating pressure and flow rate is given by:

$$q = K * P^{x} \tag{1}$$

where

q= emitter flow rate (L/h),

K = emitter discharge coefficient,

P= operating pressure (kPa), and

x= emitter discharge exponent.

The measured irrigation principle is satisfied for a particular zone if and only if all the emitters in the zone have the same emitter discharge exponent for the operational pressure range for the zone. Hence, a combination of different emitters can be used in a zone provided that they all have the same emitter discharge exponent. For measured irrigation an emitter may be a dripper, a length of micro tube, or a nozzle. The term nozzle is used to refer to a short cylindrical tube or hole for restricting the flow.

If the measured irrigation principle is satisfied for a zone, then the nozzle ratio for any two emitter nozzles in the zone is the same as the ratio of the emitter discharge coefficients.

Drippers available commercially are either online (attached externally to the irrigation tube or tape) or inline (attached internally to drip tube or drip tape). Drippers are either pressure compensating of non pressure compensating (unregulated). Pressure compensating drippers should not be used for measured irrigation unless the operating pressure is within the range recommended by the manufacturer. The emitter discharge exponent for pressure compensating drippers is almost zero within the pressure range recommended by the manufacturer (typically between 100 kPa and 300 kPa). Non pressure compensating drippers (both online and inline) are ideal for gravity feed measured irrigation. The emitter discharge exponent for most nozzles and non pressure compensating drippers is approximately 0.5. Various lengths of micro tube can also be used for gravity feed measured irrigation provided that all the emitters for the zone are micro tubes. The micro tubes used by International Development Enterprise (IDE) have an emitter discharge exponent of 0.7. A range of nozzles is available from the measured irrigation website (see Table 1 on page 7).

Appendix 2. Measured irrigation level formula

By using irrigation to maintain the water level at the level line, the volume of water entering the evaporator must match the volume of water that evaporates, assuming that there is no overflow.

Hence, at the end of each irrigation event

$$C + R = E$$

where

C is the volume of water emitted by the control nozzle during the irrigation event

R is the volume of rainwater that has entered the evaporator since the end of the previous irrigation event, and

E is the volume of water that has evaporated from the evaporator since the end of the previous irrigation event.

Therefore

$$C = E – R$$

At the end of the irrigation event, let e be the local evaporation in mm since the end of the previous irrigation event and let r be the local rainfall in mm since the end of the previous irrigation event. Let A be the surface area of the evaporation. Then provided that the evaporator never overflows or runs dry

$$C = A * (e – r)$$

This formula says that provided the evaporator never overflows or runs dry, the volume of water emitted by the control nozzle during the irrigation event is directly proportional to the net evaporation $(e – r)$ since the end of the previous irrigation event.

Let V be the volume of water emitted by one of the emitters during the irrigation event. Then from the definition of the nozzle ratio and the fact that all emitters are at the same level (and hence the same pressure)

$$V = N_E * C$$

where N_E is the nozzle ratio of the emitter to the control nozzle. Hence

$$V = N_E * A * (e – r) \qquad (1)$$

where

V is the volume of water emitted by one of the emitters during the irrigation event,

N_E is the nozzle ratio of the emitter nozzle to the control nozzle,

A is the surface area of evaporation,

e is the local evaporation in mm since the end of the previous irrigation event, and

r is the local rainfall in mm since the end of the previous irrigation event.

Formula (1) is important because it proves that the second and third conditions are satisfied in the definition of measured irrigation:

The application rate for each plant throughout the year is directly proportional to the current net evaporation rate and is independent of the pressure, the flow rate, the irrigation frequency and the duration of the irrigation event.

If the net evaporation rate is known, one can independently set the application rate for each plant.

Monthly statistics for evaporation and rainfall in Australia are available from the Bureau of Meteorology (BOM). Provided you have access to historical data for the mean monthly evaporation and the mean monthly rainfall in your locality, this information can be used to predict the application rate (litres per week) for each of the nozzles in Table 1.

$$w_i = N_E * A * max(0, e_i - r_i) * 7 / n_i \qquad i = 1, 2, 3, \dots , 12 \qquad (2)$$

where

w_i is an estimate of the weekly application rate for the nozzle in month,

e_i is the BOM mean monthly evaporation in month i,

r_i is the BOM mean monthly rainfall in month i, and

n_i is the number of days in month i.

Formula (2) is called the **measured irrigation level formula.**