Measured Irrigation from Scratch 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 scheduling paradigm and the implications for water-efficiency and energy-efficiency are significant.

Measured irrigation is a drip irrigation scheduling method that satisfies the following two conditions:

1. Variations in the water usage throughout the year are controlled by the prevailing net evaporation rate (evaporation minus rainfall).
2. The volume of water emitted by each dripper during an irrigation event is controlled directly without the need to control the flow rate or the duration of the irrigation event.

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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 emitted by a dripper during the irrigation event is controlled by using drippers with a specified flow rate and then using the duration of the irrigation event to control the volume. The acceptance of this drip irrigation scheduling 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 emitted by a dripper during the irrigation event.

Definition of measured irrigation

Measured irrigation is a drip irrigation scheduling method that satisfies the following two conditions:

- *Variations in the water usage throughout the year are controlled by the prevailing net evaporation rate (evaporation minus rainfall).*
- *The volume of water emitted by each dripper during an irrigation event is controlled directly without the need to control the flow rate or the duration of the irrigation event.*

Note that the term **water usage** refers to the number of litres per week (or litres per month) used by the irrigation system. The water usage for the measured irrigation is directly proportional to the prevailing net evaporation experienced by your plants. **This is a unique feature of measured irrigation.**

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. As the water pressure increases, the flow rate increases. However with measured irrigation, there is a corresponding decrease in the duration of the irrigation event to ensure that volume of water emitted by a dripper does not change.

Once the focus of attention changes from flow rate and time to volume, then the design of drip irrigation systems may change significantly. For example, the start time and end time of any irrigation event do not require a timer. The start time and end time are determined by net evaporation and water pressure, and so you can forget about time altogether. Hence an irrigation controller for measured irrigation does not include a timer.

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.

If you have already established a drip irrigation system, it is recommended that you download the following documents from the Measured Irrigation website: https://www.measuredirrigation.com.

- Unpowered Measured Irrigation Training Manual for Smallholders
- DIY Solar Measured Irrigation Training Manual for Smallholders
- Universal Measured Irrigation Controller User Manual

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, gravity feed measured irrigation can provide an automated irrigation system that delivers a measured volume of water to each plant.

Irrigation zones

An irrigation application is often subdivided into irrigation 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 irrigation zones are needed whereby each zone is irrigated at a different time.

For gravity feed irrigation the flow rate from the drippers (non pressure compensating) 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 be the choice of a suitable pump.

Conventional pressurised drip irrigation systems usually use pressure compensating drippers designed to deliver a relatively constant flow rate within a specified range of pressures, for example, 100 kPa to 300 kPa. This is a big advantage on sloping and it also allows for much longer laterals.

The downside of pressurised drip irrigation is the cost and maintenance. Because measured irrigation is very simple, there are fewer things to go wrong. You don't need a pump, you don't need a timer, and hose clamps are not needed due to the low pressure. You will save time and money by installing a gravity feed measured irrigation system instead of a pressurised system.

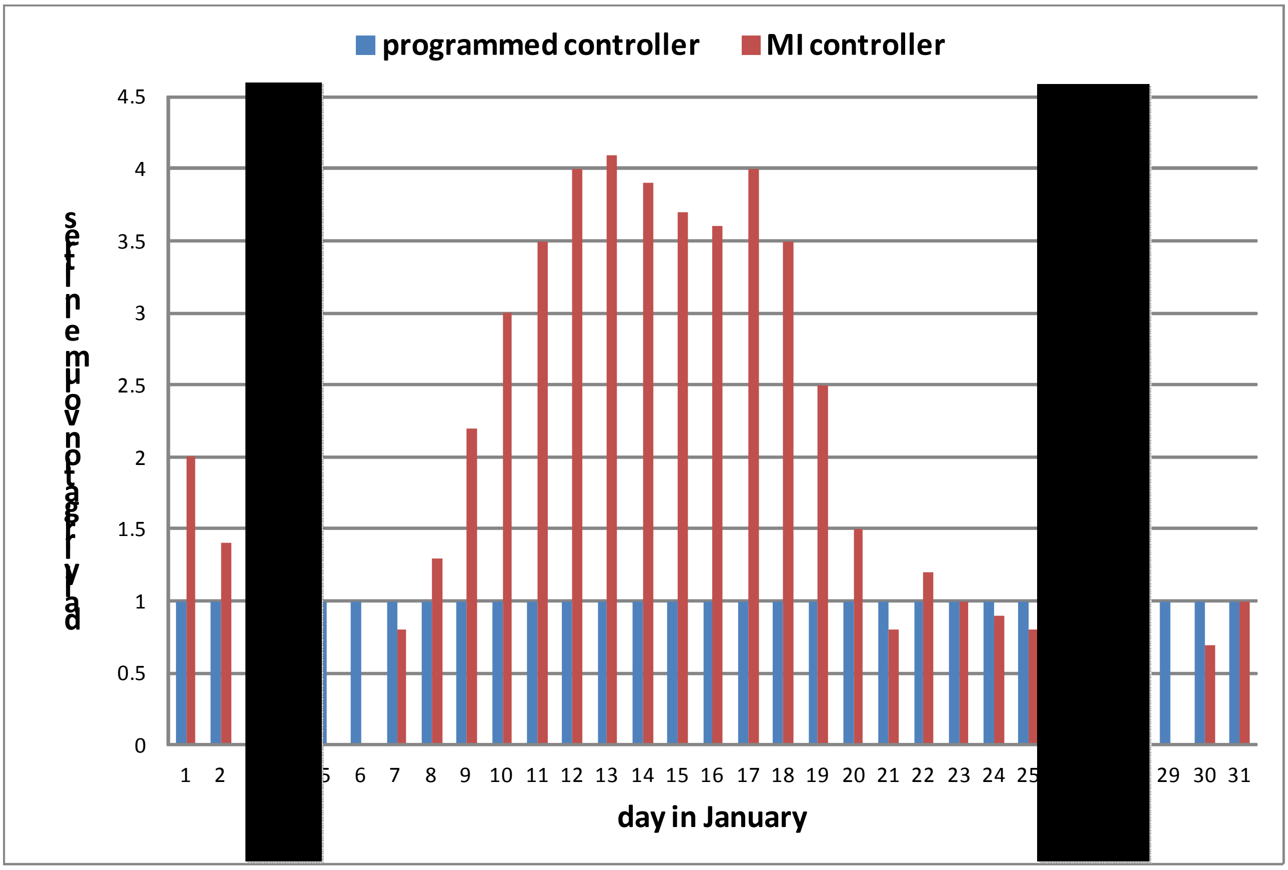
To save water and protect your plants, you would like adjust the irrigation to take account of the prevailing weather conditions. For example, when it is hot and dry you will need a lot more water. And when it rains you don't need to water the garden at all. Pressurised drip irrigation without sensors does not automatically adjust to the prevailing weather conditions, whereas measured irrigation automatically adjusts to the prevailing weather conditions. For example, measured irrigation will stop watering the garden in Adelaide during the months of June, July and August - in these months the rainfall is greater than the evaporation. The water usage is directly proportional to the net evaporation rate (that is, evaporation minus rainfall).

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 the flow rate and hence the volume of water emitted by each dripper.	The volume of water emitted by each dripper is controlled directly and is independent of the flow rate.
Unless sensors are used, the water usage does not respond automatically to the prevailing weather conditions.	The water usage responds automatically to the prevailing weather conditions.
The irrigation scheduling is controlled by an irrigation controller or timer.	The irrigation scheduling 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 to provide adequate flow to a header tank (for example, 14 watts).
Uses sophisticated technology.	Uses simple technology (fewer things to go wrong).

1.6 Measured irrigation scheduling

Suppose you have a pressurised drip irrigation system and you are using an irrigation controller (or timer) to schedule the irrigation events. Suppose that you need to go away for the whole of January, and so you program your controller to irrigate for 30 minutes every evening. Hence a 2 lph dripper will emit 1 litre every evening regardless of the weather. The chart below shows typical daily irrigation volumes per dripper in Adelaide in January for MI irrigation scheduling compared with the programmed irrigation scheduling. 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.

Chapter 2. Unpowered manual gravity feed measured irrigation from scratch

2.1 Introduction to unpowered manual gravity feed measured irrigation from scratch

We will now discuss the design of an unpowered manual gravity feed measured irrigation system, starting from scratch.

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 poly pipe with online drippers or drip line attached to the poly pipe. The drip line may be drip tube or drip tape. The drippers should be unregulated (non pressure compensating). All drippers 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 a dripper drips water into the container during the irrigation. This dripper is called the control dripper and it may be adjustable. The container is called the evaporator and a level line is marked on the inside of the evaporator about 1.5 cm below the overflow level.

Control dripper and evaporator

When the water level in the evaporator 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. 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.

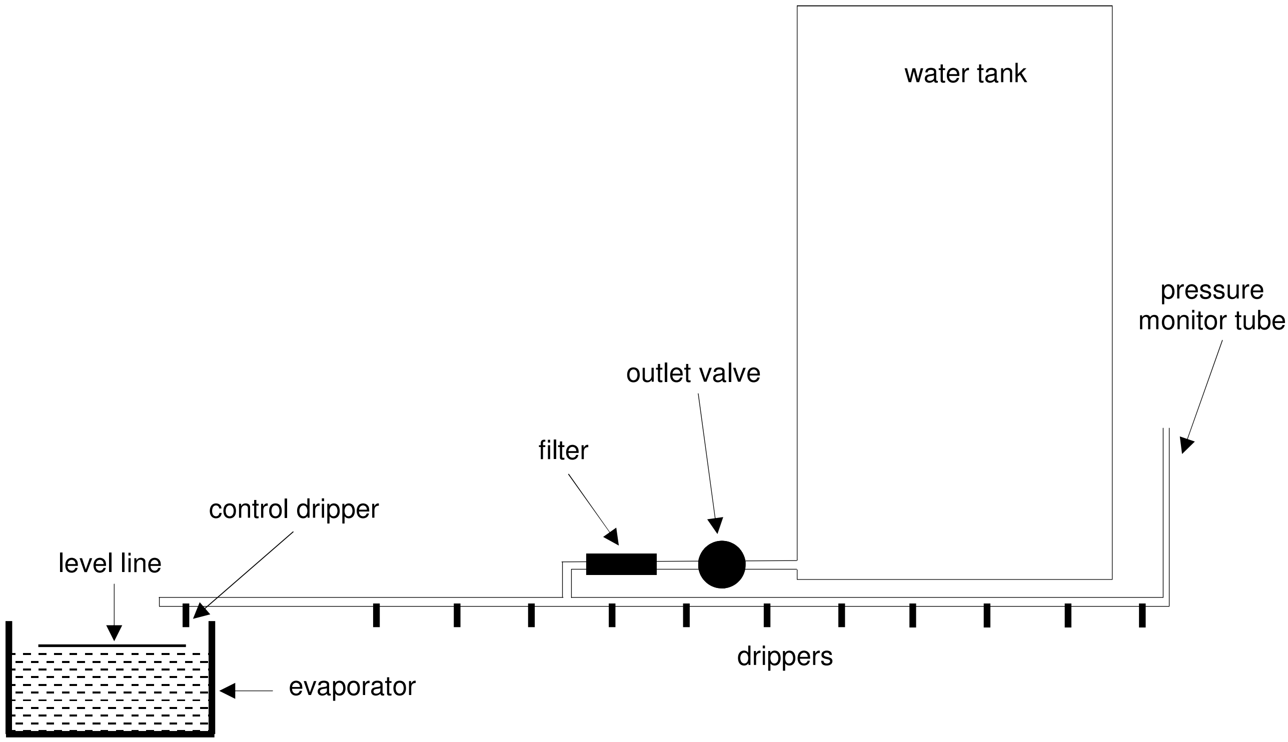
Pressure monitor tubes

For gravity feed irrigation the pressure should be the same at all the drippers, 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. If the variations in pressure are unacceptable, the diameter of the poly pipe within the zone can be increased.

Pressure monitor tubes may be purchased from the Online Shop at the Measured Irrigation website: https://www.measuredirrigation.com/product-page/pressure-monitor-tube.

Pressure monitor tube indicating the water pressure in the zone

2.2 Schematic diagram for unpowered manual gravity feed measured irrigation



2.3 Water usage (litres per week) for measured irrigation

By using irrigation to maintain the water level in the evaporator 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 water usage (litres per week) for each of the irrigation drippers in your irrigation application.

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

where

w_i is an estimate of the weekly water usage for the irrigation dripper in month *i,*

R is the ratio of the flow rate of the irrigation dripper to the flow rate of the control dripper. *R* is referred to as the nozzle ratio.

A is the surface area of evaporation,

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

r_i is the 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 formula** and it is derived in Appendix 2.

Note that these estimates of the water usage for the drippers depend only on the nozzle ratio, the surface area of evaporation, and the monthly evaporation and rainfall 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.

2.4 Installing unpowered manual gravity feed measured irrigation from scratch

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&t.

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

Unpowered manual gravity feed measured irrigation is installed as follows:

Step 1. Attach a 120 mesh 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 poly pipe to the filter so that all the plants to be watered are sufficiently close to the nearest poly pipe. Do not use hose clamps, they are not needed. To minimise head loss, 19 mm poly pipe is recommended.

Step 3. Connect the drip line (drip tube or drip tape) the poly pipe.

Step 4. Choose an evaporator and position it so that it is exposed to the same weather conditions as your plants.

Step 5. Choose a control dripper and connect it to the irrigation system so that it delivers water to the evaporator. You may need to dig a hole for the evaporator so that control dripper is at the same level as the irrigation drippers.

Step 6. Connect a pressure monitor to the irrigation system. A pressure monitor tube is used to check the pressure at any point to be confident that everything is working according to your expectations.

The above steps are used for a single irrigation zone. If you have more than one zone, each zone is connected to the water tank and has its own inlet valve, evaporator, control dripper and pressure monitor tube. The drippers in each zone should be at the same level and lower than the outlet on the tank.

Sloping ground

If the plants to be watered are at different levels, you may position a length of poly pipe so that it follows a contour line higher than all the plants to be watered.. For each plant, connect a short length of drip line (usually a single dripper) to the poly pipe and place a short length of poly pipe of the appropriate diameter over the drip line to collect the water to be delivered to the plant at a lower level. It may be convenient to a connect 6 mm flexible tube to the short length of poly pipe.

2.5 Design principles for gravity feed drip irrigation

Many smallholders use gravity feed drip irrigation to irrigate a small garden (less than an acre). When the water source is a rainwater tank or a pond, gravity feed irrigation is preferable to pressurised irrigation because you don't need to buy an expensive pump and you don't have the ongoing cost of electricity to run the pump.

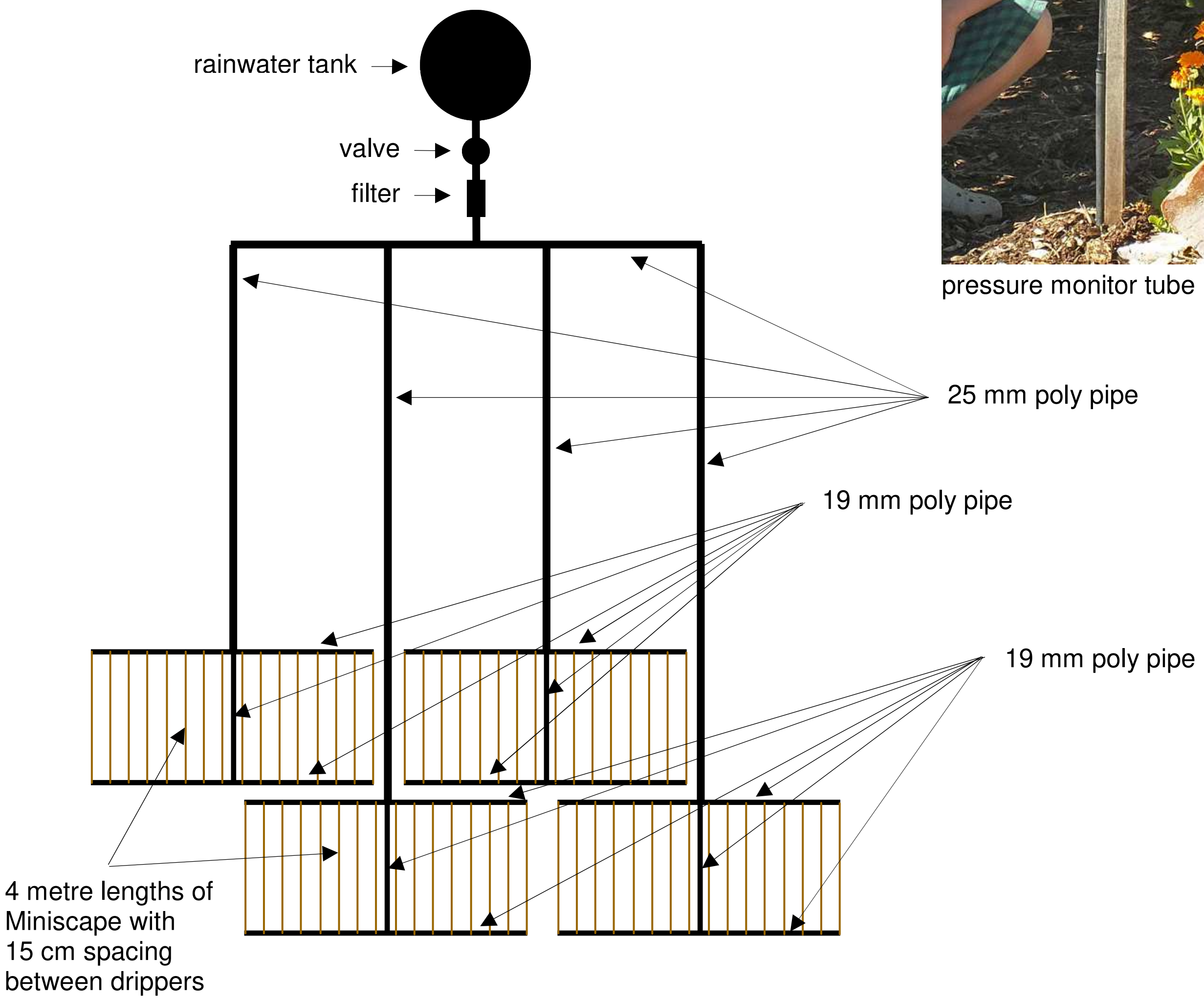
Gravity feed drip irrigation is easy to install on level or sloping ground provided you understand some important gravity feed principles:

1. Always use unregulated (non pressure compensating) drippers or drip line. For example, Netafim Miniscape (Landline 8).
2. The water source should be at least half a metre higher than all the drippers in the garden.
3. Frictional head loss can be accommodated by designing your irrigation system appropriately. For example, if you are using Miniscape with 15cm spacing between the drippers, each dripper should be no more than 3 metres away from its water supply from the poly pipe. Frictional head loss in the poly pipe can be reduced by either increasing the diameter of the poly pipe or by replacing a single line of poly pipe with multiple parallel lines of poly pipe (see the plan view below).
4. On sloping ground you need to use multiple irrigation zones such that the drippers in each zone are at approximately the same level. Each zone should have its own valve so that the irrigation of any zone is independent of the irrigation of the other zones.

The water pressure should be approximately the same for all the drippers in a zone. The pressure variation between any 2 drippers in a zone can be monitored by connecting a pressure monitor tube near each dripper. A pressure monitor tube is clear vertical tube open at the top so that you to monitor the water level in the tube. Pressure monitor tubes may be purchased from the Online Shop at the Measured Irrigation website: https://www.measuredirrigation.com/product-page/pressure-monitor-tube.

pressure monitor tube

Plan view of a single zone gravity feed drip irrigation system.



Chapter 3. Solar-powered multi-zone measured irrigation with flow-splitter

3.1 Introduction to solar-powered multi-zone measured irrigation with flow-splitter

This implementation of measured irrigation is suitable for much larger applications that require many separate irrigation zones. This implementation is ideally suited to irrigation on sloping or uneven land where each contour level will require a separate zone. 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 relative flow rates of the outlets. A flow splitter is effectively a header tank with multiple outlets.

A control dripper is connected to one of the outlets on the flow-splitter. In the pictures below the control dripper is on the right.

The inlet valve and the solenoid valve on the right

A tube delivers water from the control dripper to the evaporator. The control dripper must be open to the atmosphere at all times. The irrigation event stops automatically when the water level in the evaporator reaches the high level. The other tubes are delivering water to the various irrigation zones

Flow-splitter mounted on star pickets

Water in flow-splitter has stabilized so the inflow matches outflow

The water level in the flow-splitter will stabilized so that the outflow rate matches the inflow rate. For each irrigation zone, an adjustable valve is connected to an outlet on the flow-splitter. Note that the outlet from each valve must be open to the atmosphere at all times (for example, use a short length of oversized poly pipe to collect the water from the valve). Suppose that the inflow is increased (decreased) by adjusting the inlet valve. Then the water level in the flow-splitter will rise (fall) until the total outflow rate matches the inflow rate. Suppose that one of the outlet valves is adjusted to increase (decrease) the flow rate. The inflow rate remains the same and so the water level in the flow-splitter will fall (rise) until the total outflow rate matches the inflow rate. In order to maintain the same water level in the flow-splitter, you need to increase (decrease) the inflow rate of the input valve.

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.

3.2 Multi-zone Measured Irrigation Kit with Flow-splitter

The kit consists of the following components and is available in Australia only from the Measured Irrigation website: https://www.measuredirrigation.com/product-page/multi-zone-mi-with-flow-splitter.

Measured Irrigation from Scratch Manual	1
waterproof solenoid valve 12V 5W	1
waterproof control box with light sensor	1
level sensor with 3 probes	1
evaporator	1
filter – 120 mesh	1
inlet valve	1
pump 12V 14W	1
adjustable control dripper	1
9mm adjustable valve	8
2mm adjustable valve	4
Netafim Miniscape drip line with 0.15m dripper spacing (metres)	8
flow-splitter with 25 outlets	1
pressure monitor tubes	4
electrical irrigation cable - 3 strand (metres)	10
waterproof connectors for electrical wire	9
screw connectors for electrical wire	10
light-proof cover for flow-splitter	1

The kit does not include the solar panel and the battery.

Note that the solar panel and the battery may be replaced by a 12V 5A power adaptor.

Pump 12V 14W

Evaporator and level sensor with 3 probes

Light-proof cover protecting the flow-splitter

3.3 Installing Multi-zone Measured Irrigation Kit with Flow-splitter

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 irrigation controller to the battery, solar panel, pump, solenoid valve and level sensor. 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 irrigation controller to the battery, solar panel, solenoid valve and level sensor. 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. Attach the adjustable control dripper to an outlet on the flow-splitter and use a length of 6 mm flexible tube to connect the control dripper to the evaporator. Ensure that the control dripper outlet is open to the atmosphere.

Step 6. 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).

Step 7. For each zone, connect a network of poly pipe from the flow-splitter so that all the plants to be watered are close to the nearest poly pipe. Do not use hose clamps, they are not needed. To minimise head loss, 19 mm poly pipe is recommended. As the distance from the water tank to the zone increases, you may need to increase the diameter of the poly pipe to compensate for head loss. To irrigate your plants, connect various lengths of Miniscape (or any other non pressure compensating drip line) to the poly pipe.

Step 8. For each zone, connect a pressure monitor tube to the poly pipe in the zone. A pressure monitor tube can be used to check the pressure at any point in the zone to be confident that everything is working according to your expectations.

Step 9. For each zone, connect an adjustable valve (9mm or 2mm) 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 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 with respect to control dripper. Note that all valves should be at the same level as the control dripper and should be open to the atmosphere.

Step 10. For normal operation (assuming a solar panel is used) the switch on the irrigation controller should be set to **ON night only** so that irrigation starts after sunset. Set the switch to **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, remove some water from the evaporator to start watering.

Step 11. You should cover the flow-splitter with a light-proof cover to prevent the formation of algae.

Zones on level ground

To ensure that the pressure is the same at all drippers in the zone, the drippers should be at the same level. You can use pressure monitor tubes to check the pressure at any dripper and if variations in pressure are unacceptable you can increase the diameter of the poly pipe or decrease the length of the drip line.

Zones on sloping ground

Position a length of poly pipe so that it follows a contour line higher than all the plants in the zone. Attach a short length of drip line (one or two drippers) and use a short length of poly pipe to collect the water from the drippers. A length of 6 mm tube may be connected to the short length of poly pipe to deliver the water to a plant at a lower level. Note that the drippers must be open to the atmosphere.

Note 1

If water is overflowing at a valve attached to the flow-splitter, there may be pockets of air trapped at high points in the poly pipe. If you can't remedy the situation by physically removing the high points, you may need to insert an air relief valve at one or more of the high points. To insert an air relief valve, simply cut the poly pipe at the high point and insert a tee and a vertical piece of poly pipe 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 poly pipe of greater diameter (for example, change from 13 mm poly pipe to 19 mm poly pipe) or
- Raise the level of the flow-splitter

Note 2

There are 12 colour-coded wires coming from the irrigation controller. The wires should be connected as follows:
red wire connects to the positive lead from the battery.
black wire connects to the negative lead from the battery.
dark blue wire connects to the positive lead from the solar panel.
dark green wire connects to the negative lead from the solar panel.
purple connects to the white wire from the level sensor (reference probe).
orange connects to the yellow (or red) wire from the level sensor (high probe).
brown wire connects to the black wire from the level sensor (low probe).
yellow wire connects to the solenoid valve and the positive lead from the pump.
white wire connects to the solenoid valve and the negative lead from the pump.
grey wire connects to the black lead from the light sensor.
light pink wire connects to the white lead from the light sensor.
light blue wire connects to the red lead from the light sensor.

If you ever need to replace the circuit board inside the irrigation controller, follow the instructions below:
Connect the **Lo** terminal on the board to the brown wire.
Connect the **Ref** terminal on the board to the purple wire.
Connect the **Hi** terminal on the board to the orange wire.
Connect the **Bat +** terminal on the board to the Load positive terminal on the charge controller.
Connect the **Bat –** terminal on the board to the Load negative terminal on the charge controller.
Connect the **Com** terminal on the board to the middle terminal of the 3-way switch
Connect the **NO** terminal on the board to the yellow wire from the solenoid valve and the pump.

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.

As you increase the wattage of the solar panel, is recommended that you increase the storage capacity of the battery. If the irrigation stops before the water level has reached the high probe, it indicates that you may have insufficient storage capacity in the battery.

Note 4

If you decide that for all zones your plants are getting too much water during the irrigation event, increase the flow rate of the adjustable control dripper. On the other hand, if you decide that for all zones your plants are not getting enough water, then decrease the flow rate of the adjustable control dripper.

Chapter 4. Single-zone gravity feed measured irrigation on sloping land

4.1 Introduction to single-zone gravity feed measured irrigation on sloping land

So far it has been required that all the drippers (non pressure compensating) within a zone be at approximately the same level. For this implementation of measured irrigation on sloping ground the drippers are allowed to be at different levels. In order to control the water usage for drippers at different levels, this implementation assumes that the head of water at the control dripper is maintained at a constant level.

Suppose that there are *N* levels and that each irrigation dripper is at one of the levels. The irrigation drippers and the control dripper are not at the same level, and it can be used to show that

$$q_i = q_c * (h_i / h_c)^x$$

where

q_i is the flow rate of the irrigation drippers at level i ($i = 1, 2, \ldots, N$)

q_c is the flow rate of the control dripper

h_i is the head of water at level i,

h_c is the head of water at the control dripper, and

x is the emitter discharge exponent (see Appendix 1).

If the water supply is a dam or reservoir at a higher level, then the head of water 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 valve (or a float switch) 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.

Let s_i be the spacing between the laterals on level i ($i = 1, 2, \ldots ,N$). After the spacing s_1 between the laterals at level *1* has been set, the spacing s_i between the laterals at level i can be adjusted to ensure that the application rate (litres per square meter) is the same at every level. It can be shown that the application rate on level i is the same as the application rate on level *1* provided that

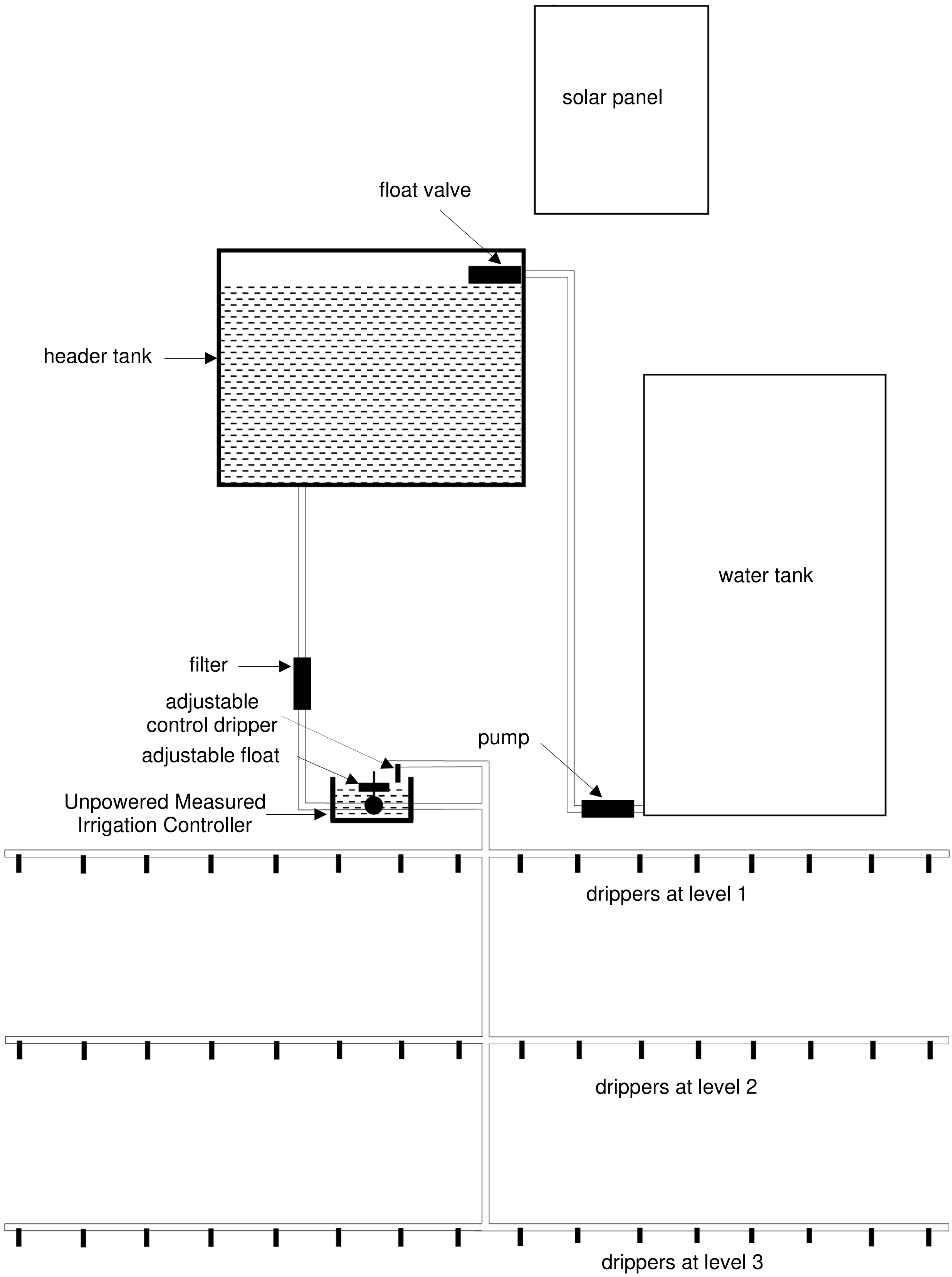
$$s_i = s_1 * (h_c / h_i)^x \quad (i = 1, 2, \ldots ,N) \qquad (3)$$

If the water supply is a dam or reservoir at a higher level, then the head of water 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 valve (or a float switch) to ensure that the water level in the header tank remains constant. Hence the head of water at the control dripper and head of water at level i remain constant, and so formula (3) can be used to calculate the spacing between the laterals at each level.

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.

The irrigation may be operated manually, or automatically with an Unpowered Measured Irrigation Controller.

4.2 Schematic diagram for single-zone gravity feed measured irrigation on sloping land



Chapter 5. Evapotranspiration and measured irrigation

Evapotranspiration-based controllers have become increasingly popular in recent years with rapid advances in information technology and decreasing prices.

The United States Environmental Protection Agency has developed criteria for the WaterSense labelling of weather-based irrigation controllers. The criteria require the water usage of the irrigation controller to be compared with the local evapotranspiration.

For all implementations of measured irrigation the water usage is directly proportional to the net evaporation from the evaporator. In this Section the water usage is compared to the local evapotranspiration.

A series of research trials were organised at the Bureau of Meteorology Weather Station at Adelaide Airport.

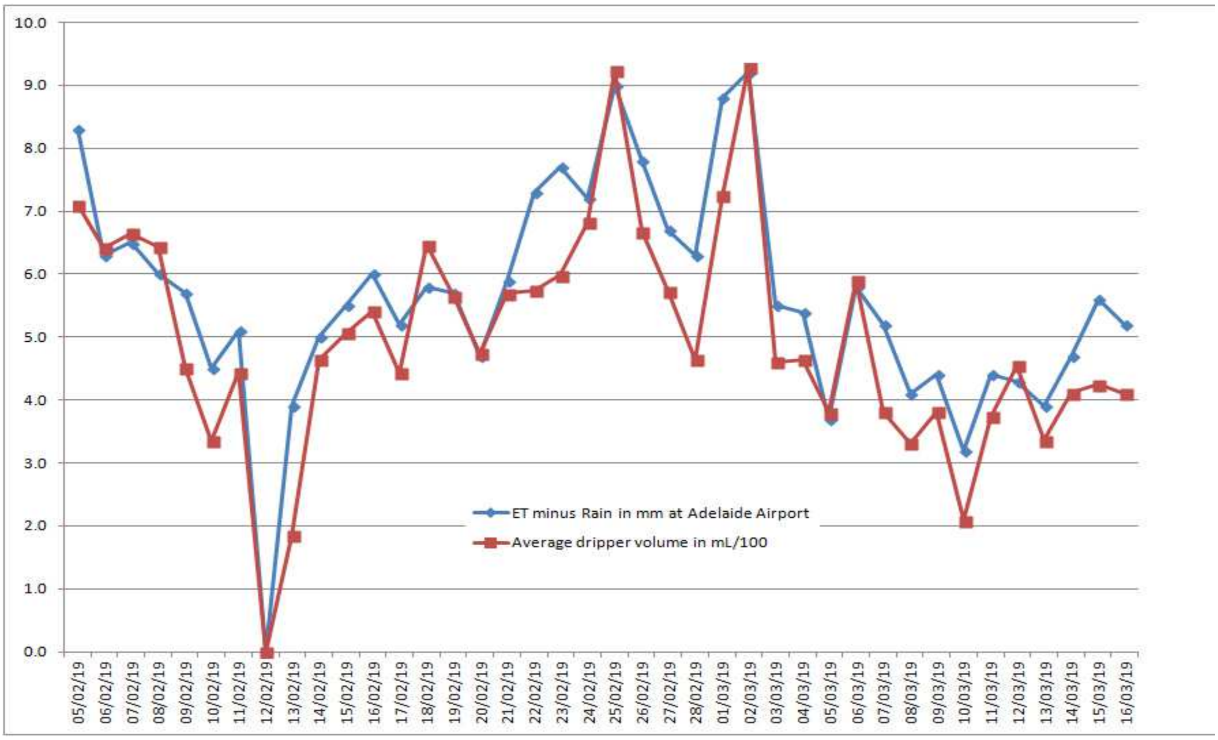
Research trials at Adelaide Airport with gravity fed water supply

An Unpowered Measured Irrigation Controller delivered water to 5 irrigation drippers and the water from each dripper was collected in a catch can. For all trials, the control dripper was two Landline Purple drippers and the 5 irrigation drippers were Landline Purple drippers. The Landline Purple dripper has a flow rate of 8 lph at 100 kPa.

The Bureau of Meteorology Weather Station at Adelaide Airport publishes daily evapotranspiration and rainfall data for the 24 hour period midnight to midnight. Daily reference evapotranspiration (ET_0) is derived from automatic weather station records and satellite measurements. The research trials were conducted for 40 consecutive days. Before midnight each night, the catch cans were emptied and the float was pressed down to start the irrigation event. The irrigation event stopped automatically when the water reached the high level. The quantity of water in each catch can was measured and corrected for any evaporation that had occurred during the irrigation event. The irrigation event was started at a time that would ensure that the irrigation event stopped at about midnight.

Results

Here is a graph of ET minus rainfall, and mean irrigation volume at Adelaide Airport from 5 February 2019 to 16 March 2019.



Daily ET minus rainfall, and mean irrigation volume at Adelaide Airport from 5 February 2019 to 16 March 2019.

The table below show the correlation between the daily evapotranspiration minus rainfall data (for 40 days) and the daily mean irrigation volumes for the 5 catch cans (for 40 days). The table also show the correlation between the daily evapotranspiration minus rainfall data and the daily irrigation volumes for each of the catch cans.

Correlation coefficient for dripper 1 volume and ET_0 minus rainfall	0.931
Correlation coefficient for dripper 2 volume and ET_0 minus rainfall	0.928
Correlation coefficient for dripper 3 volume and ET_0 minus rainfall	0.929
Correlation coefficient for dripper 4 volume and ET_0 minus rainfall	0.928
Correlation coefficient for dripper 5 volume and ET_0 minus rainfall	0.925
Correlation coefficient for mean dripper volume and ET_0 minus rainfall	0.929

The results demonstrate a strong correlation between measured irrigation discharge volumes and the prevailing evapotranspiration minus rainfall. With measured irrigation, the discharge volumes are directly proportional to the net evaporation from the evaporator. Thus there is a strong correlation between net evaporation from the evaporator and the prevailing evapotranspiration minus rainfall.

Low cost smart irrigation controllers use evapotranspiration and rainfall data from the nearest weather station**.** Such weather-based irrigation controllers are less effective when the evaportranspiration and rainfall at the weather station differ significantly from the evapotranspiration and rainfall experienced by the plants being irrigated. For example, such smart irrigation controllers are inappropriate for plants in greenhouses.

Measured irrigation controllers use the evaporation and rainfall at the evaporator which can be positioned to reflect the weather conditions experienced by the plants. In the case of a greenhouse, the evaporator would be positioned inside the greenhouse.

Chapter 6. Sophie's Patch

Sophie's Patch uses solar-powered multi-zone 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 weekly 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

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 delivering water to each of the eleven irrigation zones

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.

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 line 25cm apart and the drippers are 15 cm apart.

Chapter 19. 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
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
Fifth Ave Garden (Ascot Park), phone Roger on 0411 504410

NT
Kiranou Place Garden (Nightcliff), phone Stephanie on 0414 432245

Victoria
Yarrawonga Community Garden, phone Tom on 0438 589149
Napier Crescent Garden (Montmerency), phone Dan on 0402 465027
Gladstone Street Garden (Windsor), phone Chris on 0419 220309
Kingsley Street Garden (Ivanhoe), phone Paul on 0429 943921

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
Water Installations Pty Ltd, Mundaring, phone Ross on 0439 971213

KENYA
Contact Rob Kelly, World Vision Australia, (03) 92872724

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:

$$q = K * P^{x}$$

where

q = emitter flow rate (lph),

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.

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

Appendix 2. Measured irrigation 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

$$C + P = E$$

where

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

P is the volume of rainwater (precipitation) 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

$$C = E - P$$

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 p 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

$$C = A * (e - p)$$

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

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

$$V = R * C$$

where R is the nozzle ratio of the irrigation dripper to the control dripper. Hence

$$V = R * A * (e - p) \qquad (1)$$

This formula is important because it proves that, provided the measured irrigation principle is satisfied, the second condition is satisfied in the definition of measured irrigation, namely:

> *The volume of water emitted by each dripper during an irrigation event is controlled directly without the need to control the flow rate or 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 to predict the weekly application rate (litres per week) for each of the irrigation drippers in your application.

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

where

w_i is an estimate of the weekly water usage for the irrigation dripper in month i,

e_i is the mean monthly evaporation in month i,

r_i is the mean monthly rainfall in month i, and

n_i is the number of days in month i.

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