Acknowledgements

This handbook was produced as part of the Wildflowers and Native Plants Program within the Rural Industries Research and Development Corporation (RIRDC), which aims to improve the profitability, productivity and sustainability of the Australian wildflower and native plants industry.

This document was compiled by Agri-Sciences Queensland, Department of Agriculture, Fisheries and Forestry, with financial and technical support from the Flower Association of Queensland Incorporated (FAQI).
Foreword

This handbook has been developed to address the key principles of efficient irrigation, with respect to the wildflower industry. It provides guidelines for establishing effective irrigation of in-ground wildflowers for the cut flower market.

The goal is to provide cut flower producers with tools and information to understand and manage their irrigation system and requirements. These guidelines offer practical steps for the installation, maintenance and management of irrigation systems in ways that save water, protect water quality and maximise productivity.

This handbook was produced as part of the Rural Industries Research and Development Corporation (RIRDC) funded project, *PRJ-000336: Determining optimum irrigation scheduling requirements of key wildflower crops*. The research was conducted by Agri-Sciences Queensland, Department of Agriculture, Fisheries and Forestry with financial and technical support from the Flower Association of Queensland Incorporated (FAQI).

This report is an addition to RIRDC’s diverse range of over 2100 research publications and it forms part of our Wildflowers & Native Plants R&D program, which aims to improve the profitability, productivity and sustainability of the Australian industry.

Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at [www.rirdc.gov.au](http://www.rirdc.gov.au). Purchases can also be made by phoning 1300 634 313.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation
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1. Introduction

The importance of effective irrigation

The purpose of an irrigation system is to provide water to maintain plants in optimum condition for the purpose required. For wildflower growers this means healthy plants that produce high numbers of good quality flowers, usually with long stems, at the right time. Properly managed, high-quality irrigation systems should distribute water in a way that maintains plant health while also conserving water resources and the environment.

There are four key principles to efficient irrigation:

• The quantity of water applied is appropriate for the particular plant and soil type.
• The timing of irrigation suits the plant’s needs and the weather conditions.
• The water is applied uniformly.
• Water is applied to the plant root zone without excessive losses in the form of run-off, deep drainage, ineffective coverage or evaporation.

With recent drought conditions, which have not fully abated in some areas, addressing each and every one of these four principles is essential. Making better use of our water is the absolute priority that has driven research into the water requirements of key wildflower crops.

Purpose of the handbook

This handbook has been developed to address each of the key principles of efficient irrigation, with respect to the wildflower industry. It provides guidelines for establishing effective irrigation of in-ground wildflowers for the cut flower market.

The goal is to provide cut flower producers with tools to understand and manage their irrigation system and requirements. These guidelines offer practical steps for the installation, maintenance and management of irrigation systems in ways that save water, protect water quality and maximise productivity.

While it is recommended that any irrigation system be designed and installed by irrigation experts, it is also essential that the grower has a full understanding of the processes and maintenance issues involved. This handbook provides information about the establishment and maintenance of irrigation for wildflower cropping.

Scope of the handbook

The systems discussed in these guidelines include only those appropriate to wildflower production; no reference is made to broad-acre or similar cropping.
The guidelines specifically refer to the in-ground production of flower and foliage crops for supply to the cut flower and foliage markets. Wildflower production is a unique growing system in which perennial plants are grown in the ground, usually on built-up mounds with sufficient spacing to allow plant access by machinery, such as spray and harvesting equipment. Drip irrigation is generally used, to maximise the deep-rooting nature of the plants. Irrigation in wildflowers is intrinsically linked with soil type and soil properties which are also covered substantially within this document. While cut flower crops may also be produced via hydroponics or protected cropping operations, this handbook does not address the additional complexities of these production systems.

The handbook provides a broad overview of the type of information required to design an efficient irrigation system. It is not intended to be an exhaustive manual of the technical aspects of irrigation systems, and is not a replacement for professional advice. Other sources should be sought for detailed information on issues such as equipment specifications, system design, certification and specific maintenance processes.
2. Water supply

Before designing any irrigation system, it is important to decide which water source or combination of sources will form the main water supply for irrigation. There will be variations in pressure between these sources, which can have an impact on the choice of pipe sizes, pumping capacity and the required pressure regulation. Decisions are made based on the quantity of water required, the quantity available and its quality and cost, and federal, state and local government regulations.

Potable and non-potable water sources

Sources of water for irrigation can vary depending on the quality of water required and the location of the wildflower farm. Some sources of potable and non-potable water are described below.

Town supply

Potable water supplied from a central treatment plant, generally at mains pressure, but variations occur based on current usage and local elevation.

On-site storage

Generally non-potable water sourced from farm dams, creeks (provided there are access rights) or tanks. The associated pumping requirement is partially determined by the location and elevation of on-site storage facilities. Storage needs to have sufficient capacity (volume) to supply the maximum water requirements of the crop.

Bore water

Groundwater stored in aquifers due to seepage of rain and rivers through layers of soil and rock. This water can be accessed by installing an underground water pump. Some bore water contains chemicals and microbes that are potentially harmful to plants and people. The microbe content of water from deep, confined aquifers is generally less than that taken from shallow, unconfined aquifers as the deeper aquifers are protected by thick layers of soil. To ensure water quality is sustained, it is important that the bore is properly constructed, protected from entry of surface water and well maintained.

Important things to consider with bore water:

• Before using a deep bore, obtain a chemical analysis of the water.
• A permit must be obtained before the construction of a bore.
**Recycled water**

Sourced on-site or through central sewage treatment facilities. Using recycled water of suitable quality is a good water conservation measure.

Issues to consider with recycled water:

- Nutrient-rich water from a greenhouse could be a valuable resource, not only of water but also of fertilisers for an in-ground crop, provided plant pathogens are not present. The nutrient composition of this water must be known and the crop to be irrigated needs to be tolerant of this. Water produced after treatment and filtering at central treatment facilities is generally suitable for irrigation and non-drinking purposes.

- Not all plants and soils can be safely irrigated with recycled water. There are hazards that users need to understand to ensure the sustainable use of recycled water for irrigation. This water is under the jurisdiction of local councils who will usually provide a detailed report of the analysis of water samples from each source. These documents can provide valuable information in helping consumers decide on the suitability of water for irrigation. However, it must be noted that there are some complexities involved in the interpretation of the data.

You must contact your appropriate state or local government department to find out the correct information about bore construction and use.

Recycled water is already used in the United States, Israel and Australia for irrigating a range of crops and gardens. Irrigation of various crops with recycled water has been practiced around the world for more than 50 years. More information is available from the Recycled Water Australia website (www.recycledwater.com.au).

A bore must be installed by a licensed water bore driller.

Underground water use and bore permits are controlled by the state authority in charge of managing water resources. You must contact your appropriate state or local government department in regards to bore construction and use.

Bore pump provides access to water stored in an underground aquifer.
3. Water quality

In many cases the water source on your property may be fine for long-term use as an irrigation source for your crop. However, many natural waters contain impurities that can make them harmful to crops. These impurities can be physical (organic and non-organic debris), biological (bacteria, algae etc.), or chemical (specific ions). How these impurities affect each plant or soil type is dependent on the type and concentration of each impurity and the interaction between impurities. It is this cocktail of irrigation water that influences plant growth and nutrient uptake. Plants vary in their ability to tolerate and use poor-quality water; similarly, soils vary in their resistance to the effects of poor-quality water. Water quality should match the intended use.

In most situations impurities can be removed via filtration; however, not all chemical impurities or dissolved salts are bad for a crop. It depends on the type of salt/nutrient, its concentration and the plant’s requirements or tolerances to the different salts. Balancing the ratio or concentration of these compounds to suit your specific crop and soil type is highly important to plant growth and productivity.

Knowledge of the quality of any given water supply and the compounds dissolved in the water, assessed by chemical analysis, is essential in managing water quality in any irrigation system. This section describes the best methods to sample water from various sources, and provides an in-depth discussion on how to interpret the results from water tests.
Water sampling

Sampling should capture water that is representative of the water to be used for irrigation. Different sampling methods should be used for different water sources.

Dam or open surface storage

Avoid taking the sample from areas near the dam edge, where vegetation is growing, from near the main in-flow area or near a spillway. These areas may not represent the true water quality due to increased biological activity and water currents. A sample collected at the surface will not truly represent water quality or chemical load at the extraction-valve several metres below. Water bodies, specifically deep storage dams, are affected by thermal and chemical stratification due to seasonal temperature changes and chemical loading. Usually stratification starts at a depth of approximately 1 m below the surface, depending on water quality and clarity.
Stratification can refer to either thermal or chemical separation within the water column. Thermal stratification starts in late winter or early spring as upper water temperatures increase more quickly than deeper water temperatures. Chemical stratification occurs after thermal stratification, when chemicals or nutrients are suspended at different temperature levels within the water column. This can cause higher concentrations of a particular chemical in irrigation water or trigger algal blooms. Dams that have been stratified for a long time can cause cyanobacteria (blue-green algae) blooms.

Once dam stratification occurs it causes water quality issues that require more filtration and treatment. It takes considerable amounts of time and energy to mix the layers together and any disturbed nutrients or chemicals could lead to recurring water quality issues. Mixing can be achieved with a variety of methods such as using aerators, paddle-wheel stirrers or sub-surface pumps or by circulating the water through the irrigation system.

For deep dams (>3 m), collect samples from various depths and combine or take a sample from mid-depth of the deepest section. This is more likely to represent the quality of water being extracted for irrigation.

Shallow dams (<3 m) will have greater mixing of the water, tend to be warmer and have a larger zone of biological activity. Collect the sample from mid-depth or from 50 to 100 cm below the surface.

**Epilimnion zone**: highest zone of biological activity due to light penetration, usually warm, plenty of dissolved oxygen and aquatic life, depth depends on water quality

**Metalimnion zone**: limited biological activity, rapid decrease in temperature and dissolved oxygen. Organic matter and nutrients held in suspension

**Hypolimnion zone**: very low biological activity, oxygen consumed by decomposition of organic matter. No mixing leads to no oxygen causing anaerobic conditions. Anaerobic conditions can cause manganese, iron and phosphorus to be released from sediment, as well as hydrogen sulphide and ammonia.
**Creek/river**

Take the sample from the centre of the main flow area of the stream where there is a constant movement of water. Do not take the sample from backwaters or from sections where there is little or no flow.

**Bore**

For currently used bores, allow the water to flow for at least 15 minutes before collecting the sample. New bores should be allowed to run for a number of hours to allow the flow to become stable, and to allow new water flows to move into the suction zone. The bore driller should provide information on the time required to allow the bore to settle. For disused bores, allow the water to flow for at least 3 hours before taking the sample.

**Sample containers, storage and transport**

Check with the laboratory that will be conducting the analysis to make sure you use the correct containers for collecting and storing the samples and that you prepare and store the samples correctly prior to transport. Sample collection procedure, container and transport method are often supplied by the laboratory that will be conducting the analysis. However, if you are unable to deliver the sample in the required time, store the sample in a freezer until delivery can be made.

Generally it is necessary to supply at least 1 litre (L) in a clean bottle filled to the top. It is essential to leave no air space at the top. This ensures no loss of free chlorine or dissolved oxygen from the sample. However, some laboratories request separate samples for each analysis type. For example, bacteriological and nutrient tests may require filling only to the shoulder of the container so that additional reagents may be added.
Interpretation of water analysis for irrigation

Some of the common terms used in describing water quality and what these terms mean are discussed below.

Electrical conductivity (EC)

This is the ability or inability of a substance to serve as a channel for electricity. Pure water strongly resists the passage of an electric current. However, when salts are dissolved in water they improve its conductivity, so the greater the quantity of dissolved salts in the water, the higher the conductivity reading. EC is therefore commonly used as a reliable indicator of the degree of salinity of a water sample. It does not identify the specific dissolved salts, or the effects on crops or soils.

EC can be expressed in decisiemens per metre (dS/m), although it can also be expressed in microsiemens per centimetre (µS/cm) or millisiemens per centimetre (mS/cm). To add to the confusion, EC is sometimes also expressed as milli mhos per centimetre (mmhos/cm). Table 1 shows the EC values of a range of different water sources (all in units of µS/cm).

When checking water analysis data, ensure you understand the units used:

µS/cm = microsiemen per centimetre
mS/cm = millisiemen per centimetre
dS/cm = decisiemen per centimetre
dS/m = decisiemen per metre
mmhos/cm = milli mhos per centimetre

To convert between the various units:
1 mS/cm = 1 mmhos/cm
1 mS/cm = 1000 µS/cm
1 mS/cm = 1dS/m

Table 1. Example EC values of various water sources

<table>
<thead>
<tr>
<th>Water source</th>
<th>EC values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deionised water</td>
<td>0.5–3 µS/cm</td>
</tr>
<tr>
<td>Pure rainwater</td>
<td>&lt;15 µS/cm</td>
</tr>
<tr>
<td>Town water</td>
<td>200–&lt;800 µS/cm</td>
</tr>
<tr>
<td>Freshwater river water</td>
<td>0–800 µS/cm</td>
</tr>
<tr>
<td>Marginal river water</td>
<td>800–1 600 µS/cm</td>
</tr>
<tr>
<td>Brackish water</td>
<td>1 600–4 800 µS/cm</td>
</tr>
<tr>
<td>Saline water</td>
<td>&gt;4 800 µS/cm</td>
</tr>
<tr>
<td>Seawater</td>
<td>51 500–55 000 µS/cm</td>
</tr>
<tr>
<td>Industrial water</td>
<td>100–10 000 µS/cm</td>
</tr>
</tbody>
</table>
**Total dissolved salts (TDS)**

This is the sum of all the ions present in a sample of water and represents the total salt content of the water. The total salt concentration of the tested water is one of the most important pieces of information presented in the water analysis report. High levels of soluble salts can induce physiological drought in the plant. Roots may have an adequate water supply, but are unable to absorb the water due to osmotic pressure.

The units of TDS are parts per million (ppm) or milligrams per litre (mg/L), where the conversion is:

\[ 1 \text{ mg/L} = 1 \text{ ppm} \]

The total salt concentration can either be expressed as total dissolved salts (TDS) or electrical conductivity (EC) (see Table 2). Both measures may be presented on the report.

Conversion from TDS to EC is:

\[ \text{TDS in ppm or mg/L} = 640 \times \text{EC}_{\text{water}} \text{ in dS/m or mmhos/cm} \]

**Table 2. Salinity levels posing a hazard in irrigation water**

<table>
<thead>
<tr>
<th>Salinity hazard</th>
<th>TDS ppm or mg/L</th>
<th>EC dS/m or mmhos/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt;500</td>
<td>&lt;0.8</td>
</tr>
<tr>
<td>Medium</td>
<td>500–1 000</td>
<td>0.8–1.6</td>
</tr>
<tr>
<td>High</td>
<td>1 000–2 000</td>
<td>1.6–3</td>
</tr>
<tr>
<td>Very high</td>
<td>&gt;2 000</td>
<td>&gt;3</td>
</tr>
</tbody>
</table>

**pH**

This is a measure of the acidity or alkalinity of a water sample. The pH of natural waters normally falls in the range of 4.0 to 9.0. Soils are generally highly buffered systems and the pH of the soil would not be significantly affected by the application of irrigation water within this range. Waters having pH values greater than 8.0 would be expected to contain carbonates and bicarbonates, the calcium form of which can precipitate and block equipment such as drippers/emitters. Corrosion is more rapid in acidic waters than in neutral or alkaline waters. Irrigation with strongly acidic water may dissolve iron, aluminium and magnesium from the soil in amounts that could be toxic to plant growth.

The test for pH measures the balance between positive hydrogen ions (H+) and negative hydroxyl ions (OH-). This indicates if water is alkaline (pH >7), neutral (7) or acidic (<7).

**Turbidity**

This is a measure of water clarity, and is an indicator of how much solid matter (such as clay, silt, organic matter or micro-organisms) is suspended in the water. Highly turbid waters will need appropriate filtration to avoid blockage of irrigation emitters.
Hardness

Hardness can be defined in several ways. It may mean the water has high concentrations of iron, manganese, sulphates, carbonates and/or bicarbonates. Alternatively, it may specifically refer to the concentration of calcium or calcium carbonates. This makes it difficult to specifically define hardness; however, below are some simple limits that can be used as a guide.

**Bicarbonate** concentrations between 90 and 200 mg/L can cause increasing plant growth problems, such as leaf yellowing, and cause foliage or container staining; >500 mg/L is unsuitable for nursery irrigation. Concentrations >100 mg/L can interfere with the plant’s uptake of iron and manganese; hence symptoms of these deficiencies appear. In the case of iron deficiency, the younger leaves show yellowing due to the immobility of iron within the plant. Conversely, manganese, being a mobile nutrient, is translocated from the older leaves to the younger ones under conditions of deficiency.

**Calcium** is required for plant growth in low concentrations and is not considered toxic, but high concentrations can affect the calcium/magnesium ratio and can cause scale build-up in irrigation systems. Maintaining pH below 7.2 will prevent scale formation. Calcium carbonate (alkalinity) levels greater than 125 mg/L will cause pH to rise to unacceptable levels in longer crop cycles. Levels above 500 mg/L will cause severe problems, e.g. change soil permeability or interfere with nutrient availability, and are not suitable.

**Specific ions**

These can be toxic to plants and/or detrimental to the soil physical structure. Certain salt ions (sodium, chloride and boron) can cause direct root injury, accumulate in plant tissues and cause toxicity problems. These problems are almost always present under conditions of high total salinity. Soluble salt ions commonly found in recycled irrigation water are:

<table>
<thead>
<tr>
<th>Cations</th>
<th>Anions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (Ca²⁺)</td>
<td>Carbonates (CO₃⁻²)</td>
</tr>
<tr>
<td>Magnesium (Mg²⁺)</td>
<td>Bicarbonates (HCO₃⁻¹)</td>
</tr>
<tr>
<td>Sodium (Na⁺)</td>
<td>Chloride (Cl⁻¹)</td>
</tr>
<tr>
<td>Potassium (K⁺)</td>
<td>Sulfate (SO₄⁻²)</td>
</tr>
<tr>
<td>Iron (Fe²⁺)</td>
<td>Nitrate (NO₃⁻¹)</td>
</tr>
<tr>
<td>Manganese (Mn²⁺)</td>
<td>Borate (BO₃⁻²)</td>
</tr>
<tr>
<td></td>
<td>Phosphate (PO₄⁻³)</td>
</tr>
</tbody>
</table>

**Iron (Fe³⁺)**

Dissolved iron in water is present in the ferrous state. Except at low pH values, ferrous iron is readily oxidised on exposure to air and sunlight to ferric iron, an insoluble, reddish-brown precipitate. For information on how to take water samples for iron analysis, check with the laboratory that will be conducting the analysis.

For on-farm irrigation systems that use very small delivery outlets, the presence of iron in the irrigation water has proved to be a problem. It has been found that iron bacteria flourish in water that contains as little as 1.0 mg/L of iron. The bacteria extract the iron out of solution and convert it into a rust-coloured sludge, which quickly blocks filters and outlets.
Nitrate (NO$_3^-$)
For many crops, nitrate in the irrigation water will provide some extra nitrogen. However, nitrate-sensitive crops could be affected by nitrate concentrations greater than 22 mg/L, and problems may occur with increasing concentrations up to 133 mg/L. Above that level of nitrate, severe problems could arise. Nitrogen in the form of ammonium is seldom found in significant amounts in natural waters.

Nitrogen can be found in dams containing decaying organic matter, or in underground water contaminated with seepage from soils that have had large quantities of nitrogen fertiliser applied, or effluent from cattle feed lots or piggeries.

Sodium (Na$^+$)
Symptoms of sodium toxicity appear as burning or drying on the outer edges of older leaves, progressing inwards towards the centre. Sodium can be absorbed through roots or leaves (if sprinkler irrigation is used). Tree crops and woody perennials are most affected. Plants very sensitive to sodium may show symptoms of its toxic affect when:

- flood irrigation water has a sodium adsorption ratio (SAR) as low as 4.5
- spray irrigation water that wets the foliage has a sodium content greater than 70 mg/L or SAR greater than 3.0.

Manganese (Mn$^{2+}$)
Dissolved manganese can precipitate out to block irrigation equipment and cause black bacterial slime to grow within the irrigation system reducing efficiency. Consequences of various manganese concentrations include:

- 0.05 mg/L can lead to slime build-up in irrigation systems and is the maximum level for disposal into streams and waterways.
- 0.2 mg/L is the maximum concentration for irrigation. Higher levels are toxic to plants. Manganese toxicity is characterised by raised interveinal areas giving a puckered appearance and red, brown or black spotting of the older leaves and an uneven distribution of chlorophyll. If the toxicity continues, the plants will wilt and die prematurely.
- 1.5 mg/L will clog irrigation equipment.
Effects of water quality on soil

Using a salt-tolerant plant is not a silver bullet when it comes to using salt-laden water for irrigation. It is important to be aware that salts in the water can build up through evaporative concentration and damage both plants and soil.

Sodicity

This is the effect the irrigation water will have on the physical properties of the soil due to an accumulation of sodium (salts).

Sodium can affect plants and soils in three ways:

• by destroying soil structure. The process of structural degradation of soil aggregates when sodium dominates the exchange complex is shown in the following diagram. In the presence of moisture and exchangeable sodium, clay particles disperse rather than cling together as small peds (friable soil aggregates). This reduces water movement (permeability) and aeration in the soil. Soils with a poor structure will have a coarse, blocky or powdery texture and surface crusts will form after rain or irrigation

• by poisoning sodium-sensitive plants when absorbed by either their roots or leaves

• via calcium and/or potassium deficiencies which may occur if the soil or irrigation water is high in sodium.

Sodium absorption ratio (SAR)

The sodium adsorption ratio measured in water (SAR\textsubscript{w}) is an indicator of the relative proportion of sodium ions in a water sample to those of calcium and magnesium. SAR\textsubscript{w} is used to predict the sodium hazard.

The sodium adsorption ratio (SAR) is used to predict the potential for sodium to accumulate in the soil, if salty water was in constant use. A water sample with a high SAR and a low residual alkalinity (RA) usually has a high sodium content due to the predominance of sodium chloride.
In order to calculate the SAR\textsubscript{w} from water analysis data, it is essential to convert the units from parts per million or milligrams per litre to milliequivalents per litre:

\[
\text{meq} / l = \frac{\text{ppm}}{\text{Equivalent weight}}
\]

where equivalent weights are:

- Calcium = 20
- Magnesium = 12.2
- Sodium = 23

And the formula for calculating SAR is:

\[
SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}
\]

This parameter quantifies the ratio of sodium to calcium and magnesium in terms of the ability of sodium to dominate the soil. The lower the SAR\textsubscript{w}, the less likely the water is to cause structural degradation of susceptible soils. Table 3 outlines the level at which SAR\textsubscript{w} indicates a hazard to soil structure. The susceptibility of differing soil types to degradation is further quantified in Table 4.

**Table 3. Hazard levels for SAR**

<table>
<thead>
<tr>
<th>SAR</th>
<th>Hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10</td>
<td>Safe to irrigate with no structural deterioration, but may affect salt-sensitive plants depending on EC/TDS</td>
</tr>
<tr>
<td>10–18</td>
<td>Hazard on fine-textured soils with a high cation exchange capacity. OK on coarse-textured soils with good drainage</td>
</tr>
<tr>
<td>18–26</td>
<td>Hazard on most soils. Need to manage with amendments and drainage i.e. leaching</td>
</tr>
<tr>
<td>26</td>
<td>Not suitable for irrigation</td>
</tr>
</tbody>
</table>

**Table 4. SAR\textsubscript{w} limits based on soil type**

<table>
<thead>
<tr>
<th>Soil</th>
<th>No hazard</th>
<th>Slight to moderate hazard</th>
<th>Severe hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:1 clay</td>
<td>&lt;6</td>
<td>6–9</td>
<td>&gt;9</td>
</tr>
<tr>
<td>1:1 clay</td>
<td>&lt;16</td>
<td>16–24</td>
<td>&gt;24</td>
</tr>
<tr>
<td>sand EC\textsubscript{w} &gt;1.5 dS/m</td>
<td>&lt;16</td>
<td>16–24</td>
<td>&gt;24</td>
</tr>
<tr>
<td>sand EC\textsubscript{w} &lt;1.5 dS/m</td>
<td>&lt;6</td>
<td>6–9</td>
<td>&gt;9</td>
</tr>
</tbody>
</table>

2:1 clays such as montmorillonite, illite and smectite are the common clay minerals found in black earths and yellow sodic soils. 1:1 clays such as kaolinite are commonly found in ferrosols (formerly known as krasnozems). The SAR\textsubscript{w} at which a 2:1 clay is at risk is lower than for a 1:1 clay, as the bonds holding the 2:1 clay platelets together are more unstable in water than those of a 1:1 clay mineral.

Table 5 shows some sample SARs for water from different sources.
### Table 5. Example sodium adsorption ratios

<table>
<thead>
<tr>
<th>Source of water or effluent</th>
<th>Min</th>
<th>Mean</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Town water supplies (coastal)</td>
<td>0.2</td>
<td>1.0</td>
<td>2.3</td>
</tr>
<tr>
<td>Town water supplies (inland)</td>
<td>0.4</td>
<td>1.7</td>
<td>4.5</td>
</tr>
<tr>
<td>Groundwater (sedimentary aquifer)</td>
<td>0.1</td>
<td>0.9</td>
<td>5.2</td>
</tr>
<tr>
<td>Groundwater (granite aquifer)</td>
<td>0.5</td>
<td>1.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Groundwater (basalt aquifer)</td>
<td>0.7</td>
<td>0.8</td>
<td>2.7</td>
</tr>
<tr>
<td>Septic tank effluent</td>
<td>0.7</td>
<td>3.6</td>
<td>9.6</td>
</tr>
<tr>
<td>Sewage treatment works effluent</td>
<td>2.6</td>
<td>3.9</td>
<td>5.1</td>
</tr>
<tr>
<td>Laundry water (powder detergents)</td>
<td>1.2</td>
<td>9.2</td>
<td>52.1</td>
</tr>
<tr>
<td>Laundry water (liquid detergents)</td>
<td>0.02</td>
<td>1.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Source: Dr Robert A Patterson, ‘Consideration of soil sodicity when assessing land application of effluent or greywater’, ENVIRONMENT & HEALTH PROTECTION GUIDELINES, On-Site Sewage Management for Single Households, Technical Sheet Reference: 01/7, July 2006; Lanfax Laboratories, Armidale.

### Residual sodium carbonate (RSC)

This represents the amount of sodium carbonate and sodium bicarbonate in the water and is said to be present in a water sample if the concentration of carbonate and bicarbonate ions exceed the concentrations of calcium and magnesium ions. Residual sodium carbonate is usually expressed as milliequivalents per litre (meq/L) of sodium carbonate, or as calcium carbonate on some analysis reports.

When irrigation water containing residual sodium carbonate is used on clay soils containing exchangeable calcium and magnesium, sodium from the residual sodium carbonate in the water will replace calcium and magnesium in the soil. An increase in the sodium content of a clay soil may cause structural damage.

This predicts the accumulation of sodium in the soil based on the potential precipitation of calcium/magnesium carbonate. The formula for calculating RSC is:

\[
RSC = (CO_3 + HCO_3) - (Ca + Mg)
\]

A negative RSC indicates water is unlikely to cause structural degradation. An RSC greater than 1.25 indicates a potential hazard to soil structure. Addition of a calcium source, such as gypsum, or acidification of the water prior to use may be required.

The term residual alkalinity (RA) may also be used in some analysis reports.

### Saturation index (SI)

The saturation index (SI) of water is a relationship between pH, salinity, alkalinity and hardness. It assesses the potential of the water to cause scaling and precipitation or corrosion. Scale build-up and corrosion both damage irrigation equipment. Table 6 shows the interpretation of SI values.
Table 6. Interpretation of saturation index (SI)

<table>
<thead>
<tr>
<th>SI range</th>
<th>Likelihood of scaling</th>
<th>Likelihood of corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;1.5</td>
<td>Strong risk</td>
<td>Not likely</td>
</tr>
<tr>
<td>0.5 to 1.5</td>
<td>Moderate risk</td>
<td>Not likely</td>
</tr>
<tr>
<td>–0.5 to 0.5</td>
<td>Not likely</td>
<td>Not likely</td>
</tr>
<tr>
<td>–0.5 to –1.5</td>
<td>Not likely</td>
<td>Moderate risk</td>
</tr>
<tr>
<td>&lt;–1.5</td>
<td>Not likely</td>
<td>Strong risk</td>
</tr>
</tbody>
</table>

Effects of water quality on plants

The effect water quality will have on your crop is species-specific and dependent on the plants’ tolerance to the concentrations of the compounds dissolved in the water. The visual effects of poor-quality water on a plant could range from leaf yellowing, stunted growth or poor flower production through to leaf dieback and plant death. A quick and simple method of assessing water quality is electrical conductivity (EC). The electrical conductivity of irrigation water will determine which plants can be commercially grown on an otherwise suitable site.

If the EC of irrigation water is low to medium (refer to Table 7) but plants are not producing or are in poor health then the ratio of the salts/nutrients in the irrigation water should be checked. Different quantities and combinations of fertiliser salts in irrigation water could have a positive or negative effect depending on the fertiliser ratios, plant variety, irrigation quantities and existing nutrients in the soil. For example, a typical protea requires very little fertiliser and phosphorus and potassium fertilisers should be avoided as proteas are so efficient at extracting these compounds from the soil they can poison themselves if there is an excess.

Table 7. Salinity ranges suitable for irrigation water

<table>
<thead>
<tr>
<th>Salinity hazard (dS/m)</th>
<th>Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (EC &lt;0.8)</td>
<td>No detrimental effects; suitable for most plants. Highly sensitive plants prefer an EC less than 0.35</td>
</tr>
<tr>
<td>Medium (EC = 0.8–1.6)</td>
<td>Sensitive plants show salt stress; not suitable for sensitive species. Not suitable for sub-surface or protected cropping systems unless a controlled leaching program is implemented to stop salts from building up in the root zone</td>
</tr>
<tr>
<td>High (EC = 1.6–3)</td>
<td>Salt-tolerant plants only; not suitable for moderately sensitive species. Need to dilute with freshwater for sensitive plants</td>
</tr>
<tr>
<td>Very High (EC &gt;3)</td>
<td>Very salt-tolerant plants only; halophytes are the only plants likely to survive. Must be mixed with fresh water for irrigation. Monitor EC levels regularly</td>
</tr>
</tbody>
</table>

High levels of chlorine (used for disinfection) in irrigation water can increase soil salinity over time or burn plant tissues. If a fertigation system is used, the reaction of chlorine salts must be factored in when determining fertiliser concentrations. Chlorine in irrigation water will
quickly react with iron, manganese, ammonium ions and other organic compounds before the chlorine has time to kill pathogens or before the nutrients can be taken up by the plant. These reactions can also alter the pH of the water and hence affect the pH of the soil. However, through monitoring water quality and testing the soil, growers can specifically target fertiliser concentration to suit their crop.

**Leaching requirement**

It is possible to ensure that salt levels in the soil do not exceed those of the irrigation water by leaching the salt beyond the root zone. Adequate drainage should ensure that this salt-laden water does not cause further environmental damage through evaporative build-up (as the water evaporates from the soil it leaves the salts behind).

The leaching requirement (LR) is therefore the amount of water that must be applied in excess of that required for irrigation to ensure salts are carried away from the root zone, rather than allowed to concentrate by evaporation. It is defined as the fraction of irrigation water that must pass through the root zone to control salts at an acceptable level and is derived from the following equation:

\[
LR = \frac{EC_w}{5EC_{ec} - EC_w}
\]

Where:

- \(EC_w\) = irrigation water electrical conductivity (dS/m)
- \(EC_{ec}\) = threshold electrical conductivity (dS/m) or target salinity level in root zone after irrigation

This is best described by working through an example scenario (see box).

---

**Example**

A particular flower grower may have irrigation water with an electrical conductivity of 1.2 dS/m, which would normally only constitute a medium risk to plants.

However, the grower does not want the concentration of salts in the soil to exceed a threshold of 1.6 dS/m at any time as the plants may be sensitive to this level.

Using the above equation (with \(EC_w = 1.2\) dS/m and \(EC_{ec} = 1.6\) dS/m), the leaching requirement or fraction is then:

\[
LR = \frac{1.2}{5*1.6 - 1.2} = 0.1765
\]

The result is that approximately 0.18 (or one fifth) of the applied irrigation water must pass beyond the root zone.

This means that the grower must apply 18 per cent more water than is required to replace the water in the root zone so that soluble salts can be removed by leaching and not be allowed to accumulate in the shallow surface layers.
4. Soil management

The most important step in establishment and management of an irrigation system and regime is to identify, understand and manage the soil type/s within your growing area. Soils on a property with a high water-holding capacity, ample soil depth and effective infiltration and drainage will have reduced reliance on irrigation and improved chances to fully capture, store and utilise rainfall.

The key aims in conserving water and maximising water-use efficiency through soil management are to:

- maximise the water-holding capacity of the soil by improving soil structure and depth
- capture and store as much of the natural rainfall within the soil profile as possible by improving infiltration and drainage whilst minimising run-off
- match irrigation frequency, intensity and duration to the soil type and the rooting depth of the plant.

Effect of soil type

Physical and chemical properties of soil vary according to soil texture. These soil properties will influence the rate at which water infiltrates and drains as well as the amount of water stored and available for plant use. The diagram below illustrates the way water from a drip emitter will penetrate and redistribute within the profile of different soil types. This information will contribute to determining drip emitter spacing and flow rates. A sand soil for example, will require a closer emitter spacing to ensure water stays within the root zone, as opposed to draining too deeply and beyond the zone where it can be taken up by plant roots.

Conversely, a clay soil allows a greater lateral movement of water so emitters can be spaced further apart. Flow rates should not exceed the rate at which the soil can take in water (infiltration). This will prevent water losses through surface ponding and run-off.

In order to ensure that irrigation wets to the correct depth (rooting zone), different soil types will require different scheduling techniques. For example, a heavy clay soil may require longer, less frequent irrigation to ensure that the applied water is able to reach the desired soil depth.

Alternatively, pulse irrigation may be needed to allow water to penetrate a dense soil. Sandy soil will require more frequent but shorter irrigation events, to prevent water from draining beyond the root zone.
The ideal situation is illustrated in the adjacent diagram in which dripper spacing and flow rates are matched to the soil type such that the entire root zone is wetted, with little or no water draining below the maximum depth of roots. For in-ground wildflowers, root depth should increase through time, so duration of irrigation events can be extended as the crop ages to ensure penetration of moisture deeper into the profile.

**Improving clay soil**

Clay soils have advantages and disadvantages. On the positive side, clay soils are rich in nutrients and they hold water well. However, they are also prone to compaction and waterlogging, and can be sticky when wet and tough when dry. These problems are made worse if a clay soil is cultivated when wet as this destroys the structure of the soil.

Tips for improving clay soil:
- Cultivate soil to a minimum depth of 300 mm.
- Check soil moisture before cultivating. The soil should be moist, not wet.
- Incorporating gypsum or dolomite into the soil will assist in breaking up the soil, and improve structure and the availability of water and nutrients. The quantity of gypsum should be determined after a soil test is completed. These products should only be applied to moist soil, not wet soil because, as described above, the cultivation of wet clay destroys its structure.
- Apply and incorporate organic material (compost or manure) when establishing mounds.
- Add a layer of mulch. This will break down and improve the soil structure over time (mulch should be at least 75–100 mm deep when settled).

**Improving sandy soil**

Sandy soils have low moisture and low nutrient holding capacity. However, they are well aerated and are easy to cultivate.

Tips for improving sandy soil:
- Cultivate soil to a minimum depth of 300 mm.
- Check soil moisture before cultivating. The soil should be moist, not wet.
- Add organic matter (compost or manure) to the soil and incorporate well.
- Mulch well (to 100 mm depth) to help soil retain moisture by preventing evaporation. As mulch breaks down, it improves soil structure. Replenish the mulch layer on a regular basis to maintain a minimum depth of 75 mm.
- The term **loam** refers to all the soils between sandy soils and clay soils. Loams are said to be the perfect soil for growing plants. Loams can be improved and maintained through addition and incorporation of organic matter, such as compost, mulch and manures.
A simple test to determine the soil type

You will need the following items:

- shovel or spade
- small containers or plastic bags
- tape measure or ruler
- water

To start:

- Dig up a handful of soil and place individual samples in containers or plastic bags. You will need a good handful from each location.
- Wet the soil gradually and work it in your hand until it forms a ball.
- Keep working the ball of soil in your hand until it no longer changes.
- Now slowly squeeze the soil out between your thumb and forefinger to form a ribbon (like a sausage) and measure the length of the ribbon if any.

If you end up with a firm ball shape that you can bend like plasticine, it is a clay soil.

If the soil barely forms a ball and just crumbles, it is sand.

If the soil holds together but the ball is crumbly, it is a loam.

As a guide, the soil type can be estimated from the length of the ribbon (see Table 8).

Table 8. Ribbon lengths of soil texture classes

<table>
<thead>
<tr>
<th>Soil texture class</th>
<th>Ribbon length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Clay loam</td>
<td>40–50</td>
</tr>
<tr>
<td>Loam</td>
<td>25–40</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>15–25</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>5–15</td>
</tr>
<tr>
<td>Sand</td>
<td>0</td>
</tr>
</tbody>
</table>
5. Choosing the right system

Irrigation systems will vary across locations and crops. Factors that must be considered include design, delivery systems, pumps and filtration systems. It is also important to address issues to do with disinfection and automation. Each of these aspects is described in detail below.

Design
Correct irrigation design and installation are key factors in establishing and maintaining an efficient system. A water-efficient irrigation system must apply water uniformly to where it is required without wastage due to leakage, wind drift, drainage or excessive evaporation.

An automated irrigation system should also be able to adjust to the climate and soil conditions at the time. Soil moisture sensors or rain sensors are important additions to a system, as they stop irrigation if there is sufficient moisture in the soil or it begins to rain.

Where to start
Draw a detailed plan of your property on paper showing the areas you wish to irrigate, plus details of any infrastructure (position of the house, sheds, beds, paths, tap etc.). Do not forget to include measurements and dimensions. Identify the purpose of the areas, e.g. propagation area, container growing area or in-ground area. This will help determine the type of irrigation system and flow rates needed.

Keep in mind the irrigation scheduling when drawing your plan. Identify any areas that will require irrigating at the same time. An irrigation system designed to irrigate one area at a time may not supply enough water to two or more areas simultaneously.

This plan will be used to determine what equipment and irrigation system you will require and will be useful when discussing your needs with an irrigation professional or when purchasing equipment.

Determine your flow rate
When designing a large irrigation system, the flow rate will be dependent on several factors, including sprinkler or emitter type and...
number, pump capacity, pipe specifications, elevation and plant requirements. It is best left to an irrigation professional to calculate the required flow rate and operating pressure.

However, if you are irrigating a small area or expanding an existing system, you can calculate the maximum number of sprinklers or emitters that can be efficiently run by determining the flow rate from a system tap. This is an estimate of the rate at which water flows out of your taps. Firstly, remove all fittings (hoses etc.) from one of the taps and turn it on to full capacity. Place a bucket underneath the tap and time how long it takes to fill the bucket. This will provide a rate of litres per minute, which is used to determine the correct type and amount of drippers you can operate efficiently from your system.

Seek assistance

The next step is to visit your local irrigation professional. You will need to provide them with as much information as possible regarding your crop layout and irrigation requirements. They will be able to develop an irrigation system design and determine the requirements of pump, pipe, fittings and drippers. They should also be able to provide advice on installation of your irrigation system.

It is important to discuss your requirements and likely irrigation patterns. An irrigation professional will need to know if you are planning on expanding the system so that they can choose the right hardware to match current and future requirements.

Similarly, they need to know if the irrigated areas will remain at a constant size or if the area being irrigated is likely to vary. This information will help in deciding if a fixed speed or variable speed pump is required.

They also need to know where the water will be sourced from, how far it must travel to the pump, and what the height differences are. If water sources are too far below the pump, or require too great a length of pipe to reach the pump, there is a risk that cavitation (the formation of bubbles or cavities in a liquid) will occur unless the correct pump and pipe diameters are chosen.

All pumps have a design duty point at which they operate at maximum efficiency. Your irrigation professional will determine the required duty point for your irrigation system taking into account the required pressure at the outlet, distances of travel and flow rates. They will minimise friction losses in the system by choosing pipes of an appropriate diameter (while smaller pipes are cheaper initially, the increase in work that the pump has to do to move the water through them will end up costing more than the initial saving). Once they have determined the required duty (flow rate and pressure head) it can be matched to a pump size and type that operates as closely as possible to maximum efficiency at that point.
Installation
Ideally, you should engage the services of a qualified, certified professional to install your system. Some local government areas will have specific regulations regarding irrigation system installation and use; having the system approved by a certified professional may be a requirement. Certified installers are also needed for correct documentation of your system’s efficiency for Water Efficiency Management Plan (WEMP) requirements.

The key installation steps are as follows:
• Have the growing beds prepared with any drainage or earth works completed.
• Lay out all parts prior to cutting or installing to check they all match the irrigation system plan.
• Start digging any trenches, if required.
• On completion of trench construction, lay out and join your main and sub-main pipe system as per your irrigation system plan.
• Connect to water supply and test that all sections receive water. This will also assist in flushing any debris from the system prior to connection of dripper lines.
• Once testing and flushing is completed, turn off the water and commence installing dripper lines as per the irrigation system plan.
• With all parts installed, again turn on the water and check for leaks, blockages and that all parts appear to be working correctly. You can test the flow rate for drippers using a bucket and stop watch. Check the flow rate against that recommended for that product. If you find any large discrepancies, contact your supplier to discuss possible causes.
• If all parts are working correctly and there are no leaks, you may begin filling in trenches (or applying mulch).

Delivery system
The delivery system not only refers to the sprinklers or emitters but also the distribution pipes, pumps, filters and solenoids. Choosing these components is as important as choosing the right sprinklers or emitters. If the distribution pipes or pumps cannot provide the optimum flow rate or operating pressure for the sprinklers or emitters chosen, then you could be wasting energy, water and money.

An inefficient distribution system will reduce the application uniformity, leading to a reduction in crop quality or yield. Water and nutrients are lost through excessive leaching in some areas, while there is insufficient application in others. The right delivery system will provide an efficient and effective irrigation system, while providing a good environment for root growth matched to the plant’s water requirements.

For Australian field-grown wildflowers, drip irrigation is the most widely used method of delivering water directly to the root zone. Research suggests that a larger wetted area provided by twin drip-irrigation lines will deliver water more efficiently, while actively
influencing root growth. This method, along with good irrigation scheduling, will ensure water is not wasted in the inter-row spaces or leached below the root zone.

There are numerous brands and types of drip emitters of varying flow rate which can be installed individually into irrigation lines, allowing flexibility in placement and spacing.

Alternatively, drip line can be purchased with drip emitters embedded at regular spacings. Your irrigation consultant can advise which is more appropriate for your specific needs.

Remember, your flowering plants will be in the ground for several years, so it is important to consider the longevity of chosen irrigation components.

Some important factors to consider include stability in sunlight, durability against rodents and birds, and the ease of access and maintenance.

**Pump hardware**

Preliminary design data is needed in order to determine the type and size of pumps required to operate the system. This includes such information as vertical rise (elevation), pipe sizes and lengths, and required pressure for efficient operation of emitters.

An irrigation design professional will use the above information to calculate pump requirements. They can then decide upon the required pump rating (how much work is required to lift and push water).
**Filtration**

Filtration is important to protect both the crop being irrigated and the hardware components of the system. Common particulates in irrigation systems are rust particles from inside steel pipe work and/or precipitated compounds previously in solution. Particles of soil or sand can also enter the system at the point of intake if water supplies are ‘dirty’.

The degree of filtration required is dependent on the type of irrigation system, water quality and the emitters installed. Emitter manufacturers will recommended the degree of filtration required to ensure continuous operation. An irrigation professional can provide advice on the appropriate filters to use, depending on the water quality and other system requirements.

**Disinfestation**

Any water collected on-site has the potential to contain not only dissolved salts, but also plant pathogens. If re-using water from greenhouses, the risk is greater. While some of the dissolved salts may be beneficial nutrients, other contaminants may be harmful. No matter how clean your farm and water may look there is always the possibility of pathogens finding their way into your irrigation system.

Although disinfestation systems can be expensive to purchase and install, maintaining pathogen-free irrigation water could save considerable costs in the event of a disease outbreak, not to mention the possible revenue lost if crops need to be destroyed and replanted.
Choosing a system that suits your farm will depend on the quality of your water, the irrigation system, the vulnerability of plants to disease and your management practices.

There are several types of disinfestation systems currently available, including those listed as follows:

**Chlorine**

Chlorine is effective against a wide range of pathogens, achieving rapid control. The application system is relatively simple and inexpensive to set up and operate.

The effectiveness of this disinfectant is limited by pH, with maximum efficacy occurring in a narrow pH range. The best method to determine required concentrations is to monitor the residual concentration in water post-treatment, which is also important to ensure there are no toxicity risks to the irrigated plants.

**Ultraviolet light**

UV is generally found to be effective against *Fusarium oxysporum*, *Phytophthora cinnamomi*, *Colletotrichum capsici* and *Alternaria zinniae*; however, the pre-treated water must be filtered to remove suspended particulates and tannins to ensure adequate light penetration.

Without proper filtration, UV disinfestation can be limited.
Slow sand filtration – bio-filtration
This relies upon both biological and physical activity to control pathogens. The sand filter itself provides a physical barrier to the transport of spores and nematodes but is less effective for bacteria. To compensate for this the biological component uses beneficial bacteria to attack and destroy the dangerous bacteria. There are stand-alone biological filters available that do not use sand, which can also be effective.

Heat treatment
Heat treatment requires water to be heated to 95°C for 30 seconds. This method is effective against fungi, bacteria and nematodes. However, the disadvantages are the high costs in heating and the tendency of the process to reduce the oxygen content of the water. There must also be provision for cooling the water before it is applied so that it does not burn the roots or warm the soil and thus create ideal conditions for pathogen growth.

Ultra-filtration
Ultra-filtration using ultra-fine membrane filters provides a physical barrier to solids, organic matter, fungi, bacteria and viruses without the use of chemicals. The disadvantages are the high costs in set-up and operation. Pre-filtration is often recommended to reduce problems with blockage of the ultra-fine pores, which are expensive to replace.
Ozone
Ozone is bubbled through water and reacts with impurities to produce oxygen and hydroxyl ions. Higher levels of organic matter, salts and chelates reduce its effectiveness against pathogens.

Chlorine dioxide
Chlorine dioxide is a yellow gas formed on-site by the combination of hydrochloric acid and sodium chlorite, is effective over a large pH range against algae, bacteria, viruses and fungi. Relatively low concentrations are required for effective control; however, the system is complex and again requires high capital input. Appropriate storage facilities are required for the two reagents.

Bromine
Bromine is similar in action to chlorine and is as effective against pathogens, but remains active over a wider pH range (60 per cent of bromine is still present at a pH of 8.5, while very little chlorine remains at this pH). Bromination systems require more equipment than chlorination systems but have a shorter payback time due to the lower cost of chemicals. Bromination is more effective than chlorine in situations in which the recycled water tends to have fluctuating levels of ammonium and other nitrogen-based compounds which alter the water pH.

Iodine
Iodine is virtually unaffected by pH and can control fungi and bacteria in water with a high organic and particulate loading (‘dirty’ water). Monitoring residual levels is important to minimise toxicity risk to irrigated plants.

Note: with any of these systems requiring the use of potentially hazardous chemicals, safety precautions must be taken when handling and storing chemicals. Your industry association will have best management guidelines for the onsite management of chemicals.
Automation

Control systems for irrigation have developed significantly and new technologies are constantly being released onto the market, to make the task of irrigating as efficient and automated as possible. Simple systems can operate on a timer basis, with the requirement for manual over-ride during rainfall. More advanced systems utilise rain sensors, soil moisture and/or plant sensors to trigger or prevent irrigation events, based on the needs of the plant.

The control system you purchase will depend on the number of irrigation zones you have, whether you use soil or plant sensors, or intend to expand or upgrade at a later date. Some of the more advanced control systems are computer based, which can record irrigation times and sensor data. This data can be very useful when refining the irrigation scheduling, determining how much water a crop needs or for calculating the return (yield) for resources used, such as water and electricity.
6. Irrigation scheduling

The timing of irrigation needs to meet the changing water demands of the plant and the moisture level of the soil. The key factors to consider are the water use characteristics of the plant, climate and weather conditions, soil moisture level and soil water storage.

Scheduling irrigation in accordance with the requirements of the plants and with soil or growing media properties will not only save water and energy costs due to reduced pump operation, but can also provide an optimum growing environment for the plants. Choosing which irrigation scheduling method best suits your farm will depend on your irrigation system, irrigation controller and management practices.

Three common scheduling methods are described below.

Timed or calendar scheduling
Although this is the most common and easiest scheduling method, it uses the most water as it relies on an intimate knowledge of plant requirements on any given day and under all weather conditions and does not auto-adjust for weather conditions. Integrating an electronic rain gauge will help to reduce water use by terminating irrigation during rain events.

Evapotranspiration scheduling
Evapotranspiration (ET) refers to the amount of water lost to the atmosphere by evaporation from the soil and transpiration by the plants. ET scheduling is more water efficient than timed scheduling as it only replaces the amount of moisture lost in the previous 24-hour period. This method will require either a manual evaporation pan (Class A) or an electronic weather station to calculate ET. Alternatively, you can obtain ET values from your official local weather station if it represents weather patterns similar to those for your farm. Although some advanced irrigation controllers with attached sensors can be programmed to monitor ET and adjust irrigation accordingly, most systems will require manual adjustment and an understanding of crop water use or crop factor. This is explained in further detail later in this manual.

Soil moisture sensors and tensiometers
Soil moisture sensors monitor the water/moisture level held in the soil profile, which is measured as millimetres of water per volume of soil. Tensiometers simulate the action of plant roots by indicating how easily the water can be extracted from the soil by the plants, with values provided in units of psi or kPa. Both monitors are available as stand-alone manual units or as electronic versions that can be integrated into the system. Manual units will require daily monitoring and regular maintenance, while electronic units only need periodic maintenance and calibrating at installation.
With more advanced programmable irrigation controllers, soil moisture sensors can be used to initiate or terminate irrigation according to water loss from the soil via plant water uptake and soil evaporation. Setting the soil moisture trigger points requires an understanding of the water-holding capacity of the soil. When this has been determined, the highest and lowest soil moisture levels in the root zone can be set to provide a constant soil moisture range. This method avoids the affects of water stress on the plants and allows irrigation to be adjusted according to plant need.

Tensiometer used to indicate the availability of water in the soil

Electronic soil moisture sensors for determining the quantity of water in the soil

Enviroscan soil moisture sensor capable of logging data and integrating with irrigation controllers
**How much water can be held by the soil?**

Chapter 4 explains how soil type can be determined. Once this is known, it is important to consider the soil’s ability to hold water, which varies with every soil. Water is stored within the pore spaces between particles. There is a huge variation in particle size and particle distribution amongst the different soil types (which vary between farms and often within the same farm). For this reason, the information presented here necessarily includes generalisations that are designed to act as a guide only.

Although the following section refers to mineral soils, the principles discussed are the same for organic growing media; however, suppliers of growing media should be able to provide details on the physical characteristics of their products.

**Available water-holding capacity**

The volume of water that can be stored in soil typically ranges from 6 to 20 per cent of total soil volume. This is generally expressed as a percentage on a volumetric basis or millimetres water per centimetre of soil. So, 10 per cent moisture content equates to 10 mm over a 10 cm depth of soil. However, only some of this water will be available to the plant. Some pores are so small that the water is held too strongly to allow extraction by plant roots. The water content at which a plant can no longer extract water is termed the ‘permanent wilting point’. Irrigation based on volumetric water content should be set to occur well before this level of deficit is reached.

**Determining stored water**

An understanding of the depth to which plant-available water can be stored in the soil is the foundation of good irrigation planning.

Stored water is determined in the following way:

\[
\text{Stored water} = \text{root zone depth (mm)} \times \text{available water capacity (mm/cm)}
\]

**Table 9. Water retention values for soils**

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Field capacity (% vol/vol)</th>
<th>Permanent wilting point (% vol/vol)</th>
<th>Available water (% vol/vol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well-structured clay</td>
<td>50</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Clay</td>
<td>38</td>
<td>24</td>
<td>14</td>
</tr>
<tr>
<td>Loam</td>
<td>34</td>
<td>12</td>
<td>22</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>23</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Sand</td>
<td>9</td>
<td>2</td>
<td>7</td>
</tr>
</tbody>
</table>
How much water does the crop require?

The water used by a particular crop or plant, measured in millimetres of water, can be calculated via the crop factor method as follows:

\[
\text{Evapotranspiration (ETc) = crop factor (CF) x daily evaporation (E_{pan})}
\]

Where:
- \(\text{ETc}\) = evapotranspiration by a particular crop/plant (mm)
- \(\text{CF}\) = crop factor, which is the proportion of water used by the crop/plant compared to the water evaporated from a Class A pan
- \(\text{E}_{\text{pan}}\) = depth of water evaporated from a Class A evaporation pan (mm).

Water use is expressed as a percentage of pan evaporation (see box), or as a crop factor (CF). Values for CF typically range from 0.2 to 0.8 for most field crops. A CF of 1.0 would represent a plant that uses water at the same rate as water evaporates from the open water surface of the evaporation pan (\(\text{E}_{\text{pan}}\)).

In practice, plants use water at a rate less than this. In some extreme cases it is only 20 per cent of this rate (or CF = 0.2).

Class A

Class A refers to the specific dimensions, construction material and positioning of the pan: cylindrical with a diameter of 120.7 cm and depth of 25.4 cm; made from galvanised iron; supported on wooden base 15 cm above ground; and filled to within 6 cm of the top. It must be located above mown grass with no tall weeds, trees or bushes sheltering it in any way, and covered with wire to prevent animal access. Every 1.14 L of water added at the refill point equates to 1 mm evaporation.
There has been significant research into the crop factors of various broad-acre crops; however, at this stage crop factors have been difficult to find and/or calculate for wildflower production. As part of RIRDC Project No. PRJ-000336, an extensive literature review was conducted to define existing knowledge in water requirements for wildflower production (see Appendix A). The values found are listed in Table 10 (shown as “% of pan evaporation”) and are highly variable, ranging from 40 to 100 per cent, illustrating the importance of more research to validate and compliment these estimates.

**Table 10. Suggested irrigation volumes collated from various sources**

<table>
<thead>
<tr>
<th>Plant</th>
<th>Age / timing</th>
<th>Soil type</th>
<th>Litres/plant/day</th>
<th>Frequency</th>
<th>% of pan evaporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banksia</td>
<td>-</td>
<td>-</td>
<td>8–12</td>
<td>2–3/week</td>
<td></td>
</tr>
<tr>
<td>Boronia</td>
<td>-</td>
<td>White sand</td>
<td>1.7–10*</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Christmas bush</td>
<td>2–3 years</td>
<td>-</td>
<td>4</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Conospermum</td>
<td>-</td>
<td>-</td>
<td>2–4</td>
<td>daily</td>
<td>50</td>
</tr>
<tr>
<td>Eucalyptus</td>
<td>-</td>
<td>White sand</td>
<td>1.4*–10</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Kangaroo paw</td>
<td>-</td>
<td>White &amp; yellow sand</td>
<td>1.5*–4</td>
<td>daily</td>
<td>50</td>
</tr>
<tr>
<td>Leucadendron</td>
<td>-</td>
<td>-</td>
<td>6</td>
<td>daily</td>
<td>40–50</td>
</tr>
<tr>
<td>Scholtzia</td>
<td>-</td>
<td>White sand</td>
<td>10*</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Tea tree</td>
<td>-</td>
<td>-</td>
<td>2–6</td>
<td>daily</td>
<td>75</td>
</tr>
<tr>
<td>Verticordia</td>
<td>-</td>
<td>Lateritic gravelly sand over clay</td>
<td>12*</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Waxflower</td>
<td>0–1 year</td>
<td>-</td>
<td>3.8–7.6#</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Waxflower</td>
<td>2–3 years</td>
<td>-</td>
<td>11.4–15.1#</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Waxflower</td>
<td>3 years +</td>
<td>-</td>
<td>11.4–22.7#</td>
<td>daily</td>
<td></td>
</tr>
</tbody>
</table>

*Supplemental irrigation not total water use.

# Original volumes in gallons were converted to litres.

Sources: Barth et al. (1996); Burke and Parlevliet (2002); Considine and Growns (1998); Dalley (1995); Growns (1995); Horsman (2004); Lantzke (1995); Pro OZ Plants (2000); Reid (1992); Seaton (1999); Silber et al. (2007); Tregea (1994); Walker (1999); Worrall and Dalley (1998); and Webb (1996).
E\textsubscript{pan} values are available from the Bureau of Meteorology (www.bom.gov.au). Pan evaporation is affected by local conditions, so the best method of determining this value is by installing a Class A pan at the particular location of your crop and taking a reading each day, which should take less than 5 minutes. Alternatively, automated pans are available at a higher cost.

Class A pan evaporation could be defined as the maximum amount of water that could potentially be removed from the soil through the processes of evaporation and transpiration. Evaporation from wet soil occurs in two stages. Wet soil initially loses water at a constant rate, which depends on atmospheric demand (as determined by measurements from the Class A pan). After the surface of the soil is sufficiently dry, the rate of evaporation and transpiration are determined by soil and plant factors. However, if the available soil water stored in the profile is known, then the time when this is likely to be depleted can be estimated, based on the E\textsubscript{pan} data.

**Soil moisture monitoring and tensiometers**

Monitoring soil moisture not only helps you decide when to irrigate and by how much; it also enables you to identify water losses either through drainage, evaporation or run-off. Armed with this knowledge, you can then take steps to prevent further water-loss events. Appendix B presents some background information on soil moisture sensors.

Figure 1 presents sample soil moisture content data from an Enviroscan unit installed in a Christmas bush (*Ceratopetalum gummiferum*). This particular plot had very young plants which were not extracting water from below 10 cm. The 10 cm sensor showed some moisture removal, probably due to a combination of evaporation and transpiration (evapotranspiration). This plot also had a mulch layer consisting of a paper ‘blanket’ (EcoCover). The slight increases in moisture content each evening and night could be interpreted as condensation below the blanket. However, the data indicate a net loss of water from this shallow soil layer.

While Figure 1 shows moisture removal from a soil profile, it also provides an indication as to the potential value of the mulch layer in preventing moisture loss through evaporation from the soil surface.

If moisture losses are compared from the same depth of soil under different types of mulch, it can be seen that the EcoCover blanket is less effective than a layer of woodchip mulch (Figure 2).

In this example over the same time period, the sensor under woodchip mulch shows a net loss of 0.41 mm, while that of bare soil is 1.13 mm and EcoCover is 1.66 mm.

This indicates that the use of good quality mulch would be a management decision in support of water conservation.

Soil moisture content data can also be used to identify periods where moisture excess leads to either drainage losses or run-off. Figure 3 illustrates moisture content values from the same Christmas bush plot during a period of prolonged heavy rainfall in early 2010. Progressive wetting of the profile was observed, with significant drainage beyond 90 cm from 2 March. The prevention of such losses will be discussed in subsequent sections of this manual.
Figure 1. Soil moisture content at five depths, as logged using Enviroscan sensors on a single probe

Figure 2. Soil moisture content as logged from four Enviroscan sensors, each at 10 cm on a different probe, beneath different mulch types
Rainfall monitoring

Simple rain gauges such as those shown in this chapter can provide valuable information for irrigation scheduling. When coupled with information on the available water-holding capacity of your soil and the daily losses from evaporation (as an estimate from Class A pan evaporation) it is possible to determine the level to which rainfall has replenished the soil water content, which allows for the determination of how much irrigation water to apply.

More complicated units are available for automated collection of rainfall data, as shown in figure 4. These units are often available as a component of an automated weather station as shown below. Improvements in technology have meant that these systems are no longer price prohibitive, and some have the added advantage of linking to soil moisture sensor software.

Causes of water loss

The aim in irrigation management should be to maximise water use efficiency and minimise water loss, to ultimately improve crop productivity.

Surface run-off

This can be caused either by infiltration excess, when the rainfall rate exceeds the rate of infiltration at the soil surface, or through saturation excess, when previous rainfall has saturated the soil surface and further rainfall contributes to surface ponding and surface run-off.
Knowing your soil type and local weather patterns (predicted rainfall intensity) will provide an indication of the likelihood that run-off will be a problem. Soils with a high clay content and low rate of infiltration, those that have developed a surface crust, or those that are non-wetting are likely to produce surface run-off under medium to high-intensity rainfall events. Management practices that maximise water entry into the soil, as described in Section 4, will help prevent run-off occurrences in these situations. Where run-off occurs due to saturation of the soil profile (as in Figure 3), it may be worth considering upgrading the drainage systems.

**Evaporation**

Evaporation from a wet soil surface can equate to significant losses. As previously discussed, protection of the soil surface using a mulch layer can help to reduce these losses.

If using on-site open reservoirs, it is important to remember that there will be direct losses from the water surface. The larger the surface area, the greater will be these losses. However, the advantage in a large surface area is that a large irrigation event has a smaller impact upon the water level, ensuring sides and banks are less likely to be exposed and potentially eroded.

Evaporation from a water surface is dependent upon the temperature of the air and water, the humidity and the wind speed above the water surface. Evaporation losses can be reduced by ensuring the surface has wind protection and some degree of shading. In soils, a loss of moisture through evaporation
can cause the surface to crack, which can have a major impact on plant establishment by restricting moisture availability to the roots and increasing soil surface temperatures, adding to plant stress. This can have a major impact on plant establishment by restricting moisture availability to the roots and increasing soil surface temperatures adding to plant stress.

**Drainage**

Drainage is also a negative component of the water balance equation in that it represents water lost from the system. It generally refers to water that has moved out of the root zone, the depth of which is dependent on the vegetation type. Drainage can also occur from on-site water reservoirs, often termed ‘seepage’. Various linings can be used to prevent seepage. This is particularly important if the storage reservoir contains on-site recycled water, as any nutrients present could contaminate groundwater, which can potentially reach streams and rivers.

**System maintenance**

While drip irrigation is renowned for its efficient use of water and high uniformity, good maintenance will ensure longevity of the system and prevent inadvertent water losses.

Water quality will determine the frequency at which the system must be flushed to remove or prevent blockages. While filtration can remove physical hazards such as soil particles, chemical hazards are more difficult to prevent. Some possible water quality issues are listed below.

- Bicarbonate concentrations in excess of 2 meq/L, above a pH of 7.5, can lead to calcium carbonate build up
- Calcium concentrations in excess of 2 meq/L can cause formation of precipitates when using some phosphate fertilisers
- Sulphides in excess of 0.1 mg/L may encourage growth of sulphur bacteria and associated slime, which can cause blockages. High iron levels (in excess of 1 mg/L) can also lead to bacterial slime production.

Contact your irrigation specialist for the best treatment options for your specific situation. Always adhere to the maintenance recommendations of your system designer and/or supplier. Some simple preventative measures include:

- Ensure particulates are excluded at water intake points through appropriate filtration.
- Regularly check the system and conduct site and pump inspections to locate blockages and leaks.
- Conduct regular motor maintenance on pumps.
- Monitor flow rates, as any changes indicate that the system may need flushing.
- Ensure filters are regularly cleaned.
• Check pressure at the most distant point from the water source to ensure the system is operating within the design specifications, using an accurate pressure gauge reserved for system checking (permanently installed pressure gauges have a limited life and may become inaccurate).

A system evaluation should be conducted annually, and should include a test of flow rate, operating pressure and distribution uniformity.

It is worthwhile to check for leaks within your system on a regular basis (at least quarterly):
• turn off everything that uses water – taps, appliances and irrigation equipment
• look at your water meter – if it is still running, you have a leak somewhere on your property.
7. Mulching

Wildflower production is a unique growing system in which perennial plants are grown in the ground, usually on built-up mounds with sufficient spacing to allow access to plants by machinery, such as spraying and harvesting equipment. In this respect, a wildflower farm resembles traditional orchards or other tree-cropping systems.

Mulch is often applied to ensure surface moisture is maintained, particularly during plant establishment. There are many types of mulch available, which type is best suited to each situation will depend on soil and plant type, availability, slope of land, and cost.

During plant establishment it is important to maintain the mulch level. Young plant roots are close to the surface and susceptible to dehydration if exposed. Once the plants are established and the foliage provides shade, moisture evaporation from the soil surface is reduced. However, a layer of mulch should be maintained with mature plants as it helps to suppress weed growth, and returns nutrients to the soil as it degrades.

The slope of the land should be considered. On steep slopes, rainfall or excessive irrigation can wash the mulch from the growing beds; therefore it is important to choose a mulch product that is not easily washed away.

While all soils benefit from the addition of mulch through reduced evaporation, the added advantage for light soils is protection against erosion. Soils on steep slopes that are prone to erosion would benefit from a mulch that binds together and holds the soil in place.

Another feature of wildflower production is the grassed inter-row spaces, as shown in this chapter, to protect the soil on slopes from erosion and provide a good stable surface for equipment and staff access. In this photograph a protea hybrid is regenerating well after pruning due to adequate water stored in the root zone.

There is considerable confusion regarding mulch and compost or other organics for soil amendment.

A good mulch material should form a barrier between the air and the soil surface to insulate and prevent evaporation.

Therefore, it is important that mulch materials do not readily absorb water. Many organic soil amendments are designed to improve soil health by improving both the nutrient status of the soil and its physical properties such as water-holding capacity.

They are therefore highly water absorbing and should be incorporated into the surface layers of the soil for maximum benefit.
The photograph at left illustrates an undesirable situation in which the straw mulch has degraded to the point that bare soil and drip line are exposed.

Under these situations the soil surface and pipe water temperatures can increase, potentially causing higher evaporation during irrigation (and resulting in a wasteful loss of water).
8. Conclusion

It is hoped that this document provides new and existing growers with a reference guide for the efficient irrigation of wildflower crops for the cut flower and foliage market, offering information to allow growers to save water, protect water quality and maximise productivity.

The references and further reading provided in Chapter 11 presents the list of references from which the irrigation requirements listed in Table 10 (on page 34) originated, along with numerous other sources of information that would be valuable reading for irrigators of wildflower crops. This is not an exhaustive list, with further information becoming available regularly. RIRDC, Wildflowers Australia and the Flower Association of Queensland Incorporated regularly update information resources on their websites. Similarly, the *Australian Flower Industry Magazine*, published quarterly, contains a range of articles and information written by recognised industry experts specifically addressing the needs of the Australian cut flower and foliage industry.

While all care has been given in providing cut flower producers with tools to understand and manage their irrigation system and requirements, this handbook is by no means a replacement for seeking professional advice from trained irrigation specialists. It is recommended that any irrigation system be designed and installed by irrigation experts.

The goal of the handbook is to provide growers with the tools to understand the processes and maintenance issues involved so that they can actively work with their irrigation specialist to recognise and design for the unique nature of each individual production system.
## 9. Irrigation Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorption</td>
<td>One substance taking in another, either physically or chemically.</td>
</tr>
<tr>
<td>Adsorption</td>
<td>One substance taking up another at its surface.</td>
</tr>
<tr>
<td>AFP</td>
<td>Air-filled porosity is the free air space in a potting media that has just drained from a saturated state.</td>
</tr>
<tr>
<td>Aquifer</td>
<td>Water-bearing strata of rock or soil.</td>
</tr>
<tr>
<td>Backflow</td>
<td>Movement of water attempting to return to its source (often after being used or contaminated).</td>
</tr>
<tr>
<td>Backflow prevention valve</td>
<td>A device or valve preventing the reverse flow of water such that contaminated water cannot be sucked back into the water source. In most places, backflow preventers are required by law on all irrigation systems.</td>
</tr>
<tr>
<td>Backflushing</td>
<td>Cleaning a filter or line by reversing the flow.</td>
</tr>
<tr>
<td>Bar</td>
<td>A unit of pressure. One bar is approximately equal to 10 m head or 14.5058 psi. One bar is also approximately equal to one atmosphere.</td>
</tr>
<tr>
<td>Booster pump</td>
<td>Pump used to increase available pressure.</td>
</tr>
<tr>
<td>Capillary action</td>
<td>Water drawn through the soil or potting media by surface tension.</td>
</tr>
<tr>
<td>Class A evaporation pan</td>
<td>Open pan of a standard dimension used to measure the evaporation of water.</td>
</tr>
<tr>
<td>CNL dripper</td>
<td>Compensating non-leakage dripper.</td>
</tr>
<tr>
<td>Coefficient of uniformity</td>
<td>Measure of the uniformity of water distribution from an irrigation system. This takes into account the relationship between the wettest and driest areas to the mean application rate, expressed as a percentage.</td>
</tr>
<tr>
<td>Colloids</td>
<td>Fine particles (too small to be seen with the naked eye) that will not settle out of the water with gravity.</td>
</tr>
<tr>
<td>Controller</td>
<td>A device capable of turning on and off automatic irrigation systems. Controllers range from very simple to extremely sophisticated computer systems that utilise modems, mobile phones or radios and allow two-way communication between the controller and the units (valves, meters, weather stations, soil moisture sensors etc.).</td>
</tr>
<tr>
<td>Design pressure</td>
<td>A term that usually refers to the operating pressure at which a specific piece of irrigation equipment is designed to operate at maximum efficiency. The system is then designed to ensure each sprinkler, emitter or dripper is supplied with this pressure during operation.</td>
</tr>
<tr>
<td>Discharge</td>
<td>Flow rate of water from a pump or sprinkler or within a pipe. Discharge is measured in terms of volume per unit of time, e.g. litres per second.</td>
</tr>
<tr>
<td>Disinfect</td>
<td>Treat in a way to kill or destroy disease-carrying micro-organisms and bacteria from a person, area or surface to prevent infection.</td>
</tr>
<tr>
<td>Disinfest</td>
<td>Treat in a way to remove pests and other pathogens from an area or water body/column using a chemical compound or filtration system.</td>
</tr>
<tr>
<td><strong>Distribution uniformity</strong></td>
<td>How evenly the water from an irrigation system is distributed over an area, expressed as a percentage.</td>
</tr>
<tr>
<td>----------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Drainage</strong></td>
<td>The part of irrigation or rainfall that runs off an area.</td>
</tr>
<tr>
<td><strong>Drip line</strong></td>
<td>A narrow diameter polythene pipe with drip emitters mounted either inside the pipe (inline drip) or on top of the pipe (online drip).</td>
</tr>
<tr>
<td><strong>Drip tape</strong></td>
<td>An irrigation line with drip emitters evenly spaced within a very thin walled tube. These are generally single-use line, taken up with the crop on a seasonal basis.</td>
</tr>
<tr>
<td><strong>Drippers</strong></td>
<td>Low-flow emitters designed to drip water directly onto the soil surface, with flows typically between 1 and 8 L/h.</td>
</tr>
<tr>
<td><strong>Electrical conductivity (EC)</strong></td>
<td>Measure of the salinity of the water.</td>
</tr>
<tr>
<td><strong>Emitter</strong></td>
<td>Device in an irrigation system that discharges water, such as a sprinkler or a dripper.</td>
</tr>
<tr>
<td><strong>Eutrophication</strong></td>
<td>Enrichment of water with nutrients, mainly phosphorus, leading to abundant aquatic plant growth.</td>
</tr>
<tr>
<td><strong>Evaporation</strong></td>
<td>Water converting to vapour.</td>
</tr>
<tr>
<td><strong>Evapotranspiration</strong></td>
<td>Term to indicate the combined water losses of evaporation and transpiration over a given period. Evapotranspiration is commonly expressed in millimetres per day.</td>
</tr>
<tr>
<td><strong>FertigateApply fertiliser through an irrigation system.</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Field capacity</strong></td>
<td>Measure of the amount of water that is held in a soil 24 hours after an irrigation event. The amount of water added by the irrigation should not exceed this amount, otherwise ponding and run-off will occur.</td>
</tr>
<tr>
<td><strong>Flocculation</strong></td>
<td>Aggregation of suspended soil particles in the water, causing them to settle.</td>
</tr>
<tr>
<td><strong>Gate valve</strong></td>
<td>Valve used to control flow in pipes.</td>
</tr>
<tr>
<td><strong>Gauge pressure</strong></td>
<td>Pressure at a point in the irrigation system, as measured by a pressure gauge.</td>
</tr>
<tr>
<td><strong>Gravity flow</strong></td>
<td>The flow of water that relies on gravity to provide pressure. The water source must be located at a higher elevation than the water delivery points.</td>
</tr>
<tr>
<td><strong>HDPE</strong></td>
<td>High-density polyethylene pipe, a grade of pipe used for high-pressure irrigation lines, black in colour.</td>
</tr>
<tr>
<td><strong>Hardness</strong></td>
<td>Water containing significant amounts of calcium and magnesium, and normally expressed in terms of equivalent calcium carbonate.</td>
</tr>
<tr>
<td><strong>Head</strong></td>
<td>Energy available or required to move water in an irrigation system. Expressed in metres or kPa.</td>
</tr>
<tr>
<td><strong>Head-to-head</strong></td>
<td>A way of positioning and spacing sprinklers so that the water from one sprinkler throws all the way to the next sprinkler.</td>
</tr>
<tr>
<td><strong>Head loss</strong></td>
<td>Energy loss (reflected by a pressure drop) due to water movement in an irrigation system.</td>
</tr>
<tr>
<td><strong>Hydro-zone</strong></td>
<td>Area of an irrigation system where all the factors that influence the watering schedule are similar. Typical factors include type of plants, precipitation rate of sprinklers or emitters, solar radiation, wind, soil type and slope.</td>
</tr>
<tr>
<td><strong>Infiltration</strong></td>
<td>Rate at which water enters a given soil.</td>
</tr>
<tr>
<td><strong>Inorganic suspension</strong></td>
<td>Sand, silt and clays found in water supplies.</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td><strong>Ions</strong></td>
<td>Electrically-charged atoms, as found in soluble chemicals.</td>
</tr>
<tr>
<td><strong>Irrigation controller</strong></td>
<td>Programmable device used to automatically carry out irrigation applications and other nursery operations.</td>
</tr>
<tr>
<td><strong>Laterals</strong></td>
<td>Pipelines that hold the sprinklers or drippers.</td>
</tr>
<tr>
<td><strong>LDPE pipe</strong></td>
<td>Low-density polyethylene pipe, a grade of pipe often used for above-ground irrigation. The pipe is coloured black to resist the effects of sunlight and has a soft wall to allow fittings to be easily attached.</td>
</tr>
<tr>
<td><strong>Leachate</strong></td>
<td>Nutrient-rich water that runs out of containers after rainfall or irrigation.</td>
</tr>
<tr>
<td><strong>Leached fraction</strong></td>
<td>Percentage of water applied that is leached.</td>
</tr>
<tr>
<td><strong>Leaching</strong></td>
<td>Downward movement of soluble material through potting media or soil.</td>
</tr>
<tr>
<td><strong>LPH</strong></td>
<td>Metric measure of flow defined as litres per hour (can also be expressed as L/h). 1000 L/h is equal to 1 m³/hr.</td>
</tr>
<tr>
<td><strong>Mainline</strong></td>
<td>The pipe carrying water from the pump to the delivery system, prior to any branching. It is also used to describe the pipe on the suction side of the pump, carrying water from the source to the pump.</td>
</tr>
<tr>
<td><strong>Manifold</strong></td>
<td>Pipe with a number of inlets and outlets.</td>
</tr>
<tr>
<td><strong>MDPE pipe</strong></td>
<td>Medium-density polyethylene pipe, the grade of pipe generally used for mains water and irrigation. Potable water pipe is normally coloured blue and irrigation pipe is coloured black.</td>
</tr>
<tr>
<td><strong>Mean application rate (MAR)</strong></td>
<td>Average rate that water is applied to an irrigation block.</td>
</tr>
<tr>
<td><strong>Media</strong></td>
<td>Type of material used in a filter (such as sand) or type of mixture of material used in a potting mix (such as sand, peat or sawdust).</td>
</tr>
<tr>
<td><strong>Non-potable water</strong></td>
<td>Water not suitable for human consumption.</td>
</tr>
<tr>
<td><strong>Operating pressure</strong></td>
<td>The pressure at which an irrigation system is operating.</td>
</tr>
<tr>
<td><strong>Peak evaporation</strong></td>
<td>Highest likely evaporation rate.</td>
</tr>
<tr>
<td><strong>Peak load</strong></td>
<td>Highest demand on the system.</td>
</tr>
<tr>
<td><strong>Permeable/pervious</strong></td>
<td>Capable of allowing water to pass through.</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>Measure of acidity or alkalinity of soil or water on a scale from 1 (highly acidic) to 14 (extremely alkaline).</td>
</tr>
<tr>
<td><strong>Polyethylene</strong></td>
<td>A type of plastic used for irrigation pipe. The term is often abbreviated to ‘poly’. Poly pipe is black in colour, sometimes with a strip of a different colour for identification. It is very flexible and is usually sold in coils of 50–100 m.</td>
</tr>
<tr>
<td><strong>Ponding</strong></td>
<td>The accumulation or pooling of water in one location either caused by poor drainage or when soil is saturated.</td>
</tr>
<tr>
<td><strong>Pores</strong></td>
<td>Spaces in a potting mix that hold either air or water.</td>
</tr>
<tr>
<td><strong>Porous</strong></td>
<td>Full of pores which allow water and air to flow through.</td>
</tr>
<tr>
<td><strong>Potable</strong></td>
<td>Water suitable for human consumption.</td>
</tr>
<tr>
<td><strong>Precipitate</strong></td>
<td>Particles held in a solution disassociate due to a chemical reaction.</td>
</tr>
<tr>
<td><strong>Pressure compensated</strong></td>
<td>An irrigation emitter or dripper designed to deliver a uniform output over a large range of pressures.</td>
</tr>
<tr>
<td>---------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Pressure differential</strong></td>
<td>Difference in pressure between two points in an irrigation scheme, for example before and after a filter.</td>
</tr>
<tr>
<td><strong>Pressure gauge</strong></td>
<td>A meter for measuring water pressure.</td>
</tr>
<tr>
<td><strong>Pressure head</strong></td>
<td>A method of expressing water pressure based on the equivalent water depth.</td>
</tr>
<tr>
<td><strong>Pressure loss</strong></td>
<td>Loss of energy, as pressure, occurring when water moves through a pipe or piece of irrigation equipment due to friction. Pressure loss also occurs when water moves uphill against the force of gravity. If the total pressure exceeds the available static water pressure the water will not flow.</td>
</tr>
<tr>
<td><strong>Pressure regulator</strong></td>
<td>Device for ensuring a constant pressure in a pipe.</td>
</tr>
<tr>
<td><strong>Prime</strong></td>
<td>Allow water into the suction pipe of a pump to fully expel the air from the pipe.</td>
</tr>
<tr>
<td><strong>Psi</strong></td>
<td>Pounds per square inch, an imperial unit of pressure. There are approximately 14.5 psi to 1 bar.</td>
</tr>
<tr>
<td><strong>Pulsing</strong></td>
<td>Irrigating for short periods with a shut-off between each irrigation.</td>
</tr>
<tr>
<td><strong>PVC</strong></td>
<td>Polyvinyl chloride, a type of rigid plastic used to make water pipe, usually white in colour.</td>
</tr>
<tr>
<td><strong>Reducer</strong></td>
<td>Fitting used to change from a large diameter pipe to a smaller diameter one.</td>
</tr>
<tr>
<td><strong>Run-off</strong></td>
<td>Portion of rainfall or irrigation that flows overland into watercourses, drains or dams.</td>
</tr>
<tr>
<td><strong>Salinity</strong></td>
<td>Measure of salt concentration.</td>
</tr>
<tr>
<td><strong>Scheduling coefficient (SC)</strong></td>
<td>Measure that reflects the extra water required over a block to provide sufficient water to the driest section in the block.</td>
</tr>
<tr>
<td><strong>SDR</strong></td>
<td>Standard dimension ratio, the ratio between pipe diameter and wall thickness. A method of rating PVC pipe, the smaller the SDR number the thicker pipe wall, therefore higher pressure rating.</td>
</tr>
<tr>
<td><strong>Shroud</strong></td>
<td>Covering of metal or plastic material to protect or enclose a pipe or pump.</td>
</tr>
<tr>
<td><strong>Sodium absorption ratio (SAR)</strong></td>
<td>Relative abundance of sodium as compared to calcium and magnesium.</td>
</tr>
<tr>
<td><strong>Softness</strong></td>
<td>Water containing small amounts of calcium and magnesium, generally up to about 75 mg/L hardness (as calcium carbonate).</td>
</tr>
<tr>
<td><strong>Solarisation</strong></td>
<td>Natural process of destroying plant pathogens in potting media by using solar energy.</td>
</tr>
<tr>
<td><strong>Solenoid valve</strong></td>
<td>An electrical device which opens and closes an irrigation line under the control of the irrigation panel. Usually operated at 24V AC for safety.</td>
</tr>
<tr>
<td><strong>Sprinkler</strong></td>
<td>Emitter with higher flows which uses the pressure of the water to disperse water, in small droplets, over a set distance, or radius, from the emitter.</td>
</tr>
<tr>
<td><strong>Square spacing</strong></td>
<td>Sprinkler layout in which sprinklers are placed in a square as viewed from above, with one sprinkler in each corner.</td>
</tr>
<tr>
<td><strong>Stratification</strong></td>
<td>The development of layers within the water body along a temperature or chemical divide; a point where temperature or chemical concentrations change.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Sub-irrigation</strong></td>
<td>Applying water to the bottom of the container or directly into the root zone of in-ground plants.</td>
</tr>
<tr>
<td><strong>Sub-mains</strong></td>
<td>Pipe manifolds that connect the laterals to the block valve.</td>
</tr>
<tr>
<td><strong>Surfactant</strong></td>
<td>Substance which helps chemicals and/or water to adhere to it by changing surface tension properties.</td>
</tr>
<tr>
<td><strong>Suspended solids</strong></td>
<td>Floating objects that can cause blockages.</td>
</tr>
<tr>
<td><strong>Swale</strong></td>
<td>Waterway or drain that is usually grass-lined.</td>
</tr>
<tr>
<td><strong>System hygiene</strong></td>
<td>Method of keeping irrigation systems clean and free from unwanted organic and inorganic contaminants.</td>
</tr>
<tr>
<td><strong>Total dissolved salts (TDS)</strong></td>
<td>Amount of dissolved salts in water.</td>
</tr>
<tr>
<td><strong>Total pressure head</strong></td>
<td>Sum of all the pressure in a system incorporating all factors which increase or decrease the available water pressure at the delivery point.</td>
</tr>
<tr>
<td><strong>Transpiration</strong></td>
<td>Loss of water vapour from leaves, mainly through stomata.</td>
</tr>
<tr>
<td><strong>Turbid water</strong></td>
<td>Dirty or muddy water.</td>
</tr>
<tr>
<td><strong>Upstream</strong></td>
<td>Higher point, or a point that is against the flow.</td>
</tr>
<tr>
<td><strong>UV radiation</strong></td>
<td>Non-chemical water disinfection treatment.</td>
</tr>
<tr>
<td><strong>Vacuum relief valve</strong></td>
<td>A device which opens at low pressure, allowing air into the line to control the amount of vacuum within the line. It therefore prevents dirt being drawn into the drip pipes when the system is turned off. Frequently used on drip tapes and drip lines in contact or beneath the soil.</td>
</tr>
<tr>
<td><strong>Valve</strong></td>
<td>Device used to control water flow. Isolation valves shut off water in discrete locations, useful for carrying out repairs. Control valves turn on and off the water to the individual irrigation stations. Check valves allow the water to flow in only one direction. A master valve is the main shut-off valve for the entire irrigation system.</td>
</tr>
<tr>
<td><strong>Water absorption rate</strong></td>
<td>Rate that a growing media can absorb water into its capillary pores.</td>
</tr>
<tr>
<td><strong>Waterhammer</strong></td>
<td>Concussion that occurs in pipes when water movement is suddenly stopped or started, for example when opening or closing a valve quickly.</td>
</tr>
<tr>
<td><strong>Water meter</strong></td>
<td>Device used to measure the amount of water flowing through a pipe.</td>
</tr>
<tr>
<td><strong>Water table</strong></td>
<td>Upper limit of the portion of ground saturated with water.</td>
</tr>
<tr>
<td><strong>Zone</strong></td>
<td>A single unit or station of the irrigation system; allowing for different watering requirements and also to reduce the size of the pump and pipe work, by reducing the amount of water used at any one time.</td>
</tr>
</tbody>
</table>
10. Appendices

Appendix A. Optimum irrigation scheduling techniques for key wildflower crops: do they exist? A literature review

David Hunt and Rachel Poulter
Agri-Science Queensland,
Department of Employment, Economic Development and Innovation,
Department of Primary Industries and Fisheries, Queensland

Summary

With an increasing focus on water in recent times, more efficient use of water has become a key issue for many irrigated farms. Irrigation and irrigation scheduling has moved towards a high-tech solution of precise water application, with farm management including an accountability for all water used.

Few wildflower crops have been investigated for their water requirements or use. In many cases it has fallen to the farmer to determine the quantity of water needed—not only to ensure plant survival but also to ensure high crop quality and yield. While many of these crops are able to survive and may not even show physical signs of stress under limited water supply, their productivity and/or flower quality has been shown to be significantly reduced. Relying upon visual observation appears to be an inadequate method for irrigation scheduling, with numerous authors recommending the adoption of soil moisture monitoring.

It is apparent that it is not simply a matter of applying a set amount of water to produce a high yielding crop. Water requirements vary with factors such as soil type, location, nutrient availability and stage of plant growth, as well as the obvious variation between species and cultivars. Irrigation frequency will also depend on soil type, soil moisture retention capacity and rainfall for the geographical area of the farm, but studies have suggested irrigations should be daily in summer and reduced during winter.

Soil moisture sensors and/or evaporation values will remove some of the guess work and will help farmers to determine irrigation frequency and duration. Using soil moisture sensors such as tensiometers will provide a more accurate guide to scheduling irrigation.

The most important concept to consider is that there is no generic irrigation practice for all plants in all situations and locations. A grower needs to determine how the plants are responding to irrigation and the conditions of their specific farm to fine-tune their irrigation practice to suit the requirements of their crop. However, a review of the literature has provided guidelines as to how the plants will respond, in general terms, to certain practices. It is strongly suggested that these systems and practices are used as a guide only and that plants are regularly monitored until an appropriate irrigation practice can be identified for a particular farm and crop.
Introduction

Irrigation requirements for crops in general have been the focus of many research projects over the years. With an increasing focus on water in recent times as a direct response to the persistent drought, more efficient use of water has become a driving factor on many farms. The issue is being addressed by irrigation users, with several projects focused on water-use efficiency. However, not all wildflower crops have been investigated for their water requirements or use. In many cases it falls to the farmer to determine how much irrigation or rainfall is needed—not only to ensure plant survival but also to ensure high crop quality and yield.

Previously, the major concern in establishing a wildflower farm involved locating a geographical area that provided sufficient rainfall and had access to the market. Now, these issues are being over shadowed by the need to supplement rainfall with irrigation due to the persistent drought affecting most of the country (Seaton 1999). In the past, water was considered an infinite resource and irrigating crops was a simple matter of turning on the tap until the ground was wet or sodden. Now, irrigation and irrigation scheduling has moved towards a high-tech solution of precise water application, with farm management including an accountability for water management.

The introduction of a Water Efficiency Management Program (WEMP) is changing the way irrigators view their water storage and distribution systems. Many designers and manufacturers of irrigation equipment have spent considerable money and resources on developing highly efficient irrigation equipment. Installing an efficient irrigation system is only one half of the problem faced by farmers. To reach the full potential of water-use efficiency a farmer must now focus on providing irrigation that supplies water to a crop; when, where and in what amount the plant requires to provide the best quality and yield possible.

Research programs are assisting in identifying irrigation scheduling practices. However, each project seems to reveal an array of additional complications. For example, it has become apparent that different protea cultivars have different irrigation requirements and growth periods. It is apparent that it is not a simple matter of applying a set amount of water to produce a high-yielding crop. There are several other issues to consider in conjunction with plant water requirements; for example, soil type is a major influencing factor in the growth of certain wildflower crops. Other factors include the availability of particular nutrients within the soil and the timing of fertiliser applications.

This review is part of a larger project Determining optimum irrigation scheduling techniques for key wildflower crops, with a specific focus on Protea cv. ‘Pink Ice’ (Protea neriifolia x Protea susannae) and Christmas bush (Ceratopetalum gummiferum). This project is funded by RIRDC and the Flower Association of Queensland Industry (FAQI) and is intended to present previous research conducted into the irrigation requirements of wildflower crops. It does not include research relating to the broader cut flower industry, as that is beyond the scope of this review. It will present the findings of various projects and aims to provide some guidelines for crop irrigation.
Industry background

The wildflower industry in Australia has been expanding since the first boronia (*Boronia megastigma*) varieties were cultivated in Victoria and Christmas bush (*Ceratopetalum gummiferum*) was wild harvested in the Sydney basin in the late 1800s (Ridge Partners 2005; Carson et al. 2000). The first waxflower (*Chamelucium* spp. and hybrids) farm was established in Queensland in the 1930s. However, the wildflower industry did not gather momentum until the 1970s, when the waxflower industry moved to the Darling Downs and Lockyer Valley in Queensland, and the first protea (*Protea* sp.) plantations were established in Victoria. Since then, 250 to 300 indigenous flora species have been either wild harvested or commercially grown. However, with increasing consumer pressure and the implementation of conservation laws, many wildflowers can now be harvested only from commercial flower farms. This move from wild harvesting to commercial cultivation comes at a price as producers are faced with the need to establish economically and environmentally efficient farms. Additional challenges associated with the agronomy of such crops commonly include a slow growth rate coupled with propagation difficulties (Carson et al. 2000).

Carson et al. (2000) suggested that 150 of the previously bush-harvested species were under some form of cultivation within Australia. The remaining species, although having excellent commercial potential, were unlikely to be cultivated due to difficulties in propagation. Despite these challenges the industry has grown considerably over the last 20 to 30 years. In 1999 it was estimated that the Australian wildflower industry was valued at $45 million with approximately half of all production being exported to the global market.

A report by Ridge Partners (2005) suggested that the Australian wildflower industry had been growing at a rate of 120 per cent per year during the 1990s, but has since stabilised and is now estimated to be worth more than $50 million per year. They also estimated the global wildflower market to be valued at about $400 million, with Australian producers contributing around 12.5 per cent. However, with international trade barriers being lowered and developing nations having lower labour costs (South African nations spend as little as 3 to 5 per cent on wages), the Australian wildflower industry, which spends approximately 75 per cent of all production costs on wages, is under greater pressure to reduce costs in order to remain competitive on the global market. If increasing water costs are added to these international market pressures it is clear that the industry needs to refine its production processes to compete in the world market (Ridge Partners 2005).
Key wildflower species

Proteaceae

The Proteaceae family was named after the Greek god Proteus who was known for his ability to change his appearance and form. This aptly identifies the plants of this family as they have a variety of forms and appearance. This plant family is generically referred to as *Protea*, but also includes genera such as *Leucadendron*, *Leucospermum*, *Serruria*, *Berzelia* and *Brunia* (Reid 2008). They are grown widely throughout the southern hemisphere with cultivation in South Africa, Australia and Israel and new producers emerging in some countries of South America. They are regarded as one of the most important cultivated wildflowers and are in great demand within the cut flower industry internationally (Ridge Partners 2005).

Proteas

The *Protea* genus has 115 species of evergreen shrubs and small trees that produce a variety of coloured, cone-shaped flowerheads, made up of many small hairy flowers surrounded by colourful bracts.

The foliage is hairy, leathery and green in colour, with an undulating leaf margin. The plants prefer an open, sunny position with a mild climate and slightly acidic soils. They can tolerate some light frosts, but new plantings will require protection during the first two winters (Brown 2004).

The review of the literature has revealed that there is some misconception as to the parent varieties of proteas crossed to develop the *Protea cv. ‘Pink Ice’*. Proteafolia Pty Ltd, the original developers of the variety have confirmed that *Protea cv. ‘Pink Ice’* is a hybrid of *Protea neriifolia* and *Protea susannae* (Proteafiora 2007).

Growing proteas is a long-term investment with a period of three to four years before a substantial harvest will be produced. The correct selection of a species to suit the climate, soil type and location is one of the most important choices a grower can make. Selecting a variety purely for its marketability or sale price could end with devastating results, as extensive management and maintenance would be required if the growing environment does not suit the variety (Vogts 1989; Seaton 1999; Webb 2007).
As with any crop, ensuring an adequate water supply for economic returns is essential in this management and maintenance program.

In Queensland, proteas are harvested between November to April with peak production in February and March, while in other states the production period tends to be between February and August.

King protea (Protea cynaroides) has a harvesting period between April and October with a peak in June, August and September, while other states tend to have a harvesting period between September and January (Carson et al. 2000).
Leucadendron

Leucadendrons are native to Australia. There are a number of cultivars of *Leucadendron* species ranging in colour from yellow through to red with ‘Safari Sunset’ being the main variety produced in Queensland (Carson et al. 2000). Harvest usually takes place from April to August with a second crop in December, however in other states harvest occurs from February to April (Carson et al. 2000).
Banksia

Banksia species again, are native to Australia, with some selected long-stem forms being produced or wild harvested for the cut flower market, sometimes as a feature for dried flower arrangements (Carson et al. 2000). Since there is a wide range of species it is difficult to define specific harvest periods for Banksia; however, they are listed as having autumn and spring flowering peaks (Carson et al. 2000).
**Ceratopetalum**

The genus name *Ceratopetalum* was derived from the Greek words *ceras*, a horn and *petalon*, a petal, referring to the petal shape of one species (Brown 2004).

The species name for Christmas bush, *Ceratopetalum gummiferum*, relates to the gum the plant produces.
The *Ceratopetalum* genus has only five or possibly six species native to Australia and New Guinea.

In Australia it grows wild in the moist forests of eastern New South Wales.

Only two species currently have commercial significance: *Ceratopetalum apetalum* (coachwood) is valued for its long straight timber and *Ceratopetalum gummiferum* (Christmas bush) of which there are several cultivars in production (e.g. ‘Albery Red’, ‘White Christmas’).

The Christmas bush is valued for its attractive, shiny, soft, green foliage, which is divided into three leaflets with finely serrated margins that are initially pink or bronze in colour, and its clusters of small white or red flowers.

Generally, the flowers are initially white but when they mature the sepals change to pink or bright red in summer, usually around Christmas time, hence the common name (Worrall and Dalley 1998; Freeman and Mills 1999).

*Ceratopetalum gummiferum*, known as Christmas bush or New South Wales Christmas bush or Festival bush, has a production period between mid-October and mid-December in south-east Queensland, but this tends to be later in the cooler climates of New South Wales (Freeman and Mills 1999; Carson et al. 2000).

New plantings will take two to three years before commercial production can begin. In their natural habitat, rainforests and moist open forests, they can grow to a height of 10 m with a canopy of 2–3 m, but when cultivated rarely exceed 5 m.
Irrigation scheduling

Irrigators determine the timing and quantity of irrigation for crops through a process of irrigation scheduling, which involves estimating crop water requirements at various stages of growth and in differing climatic conditions (Qassim and Ashcroft 2006). In order to achieve this, knowledge is required as to the quantity of water that is available to the plant. This knowledge can be obtained either directly (through plant observations, observing the feel and appearance of the soil, or more accurately, soil moisture monitoring) or indirectly (by estimating water loss or accessions from weather-based data). However, as will be discussed, these estimates are based upon in-depth knowledge of individual species physiology and the extent to which evaporation drives the plant transpiration process. The terms ‘crop coefficient’ and ‘crop factor’ are employed in this scenario and will be discussed further.

Having a system to help determine irrigation scheduling is a good start, but time, money and production can be wasted if an efficient irrigation system is not used. Incorrect irrigation or poorly designed and inefficient irrigation systems can result in a reduction of flower yield and quality, and an increase in water use (Seaton 1999). One study (Hunt 2008) showed that 25 to 45 per cent of irrigation water could be saved if an appropriate efficient irrigation system is installed and managed correctly. An inefficient or non-uniform irrigation system can lead to areas being under or over-watered, causing irregular plant development and in some cases plant death. Some symptoms of incorrect or non-uniform irrigation are reduced stem growth, leaf yellowing or loss, and small flower head size (Seaton 1999; Silber et al. 2006).

Plant observation

In many cropping situations, observing the condition of plants often provides growers with an idea of when to irrigate. Changes observed include characteristics such as leaf colour, curling and/or wilting as these are the most common signs of moisture stress. Generally, as soon as these symptoms are seen the crop requires irrigating. However, once the crop has reached this state, chances are that the productivity is reduced (Qassim and Ashcroft 2006).

When considering wildflowers, the usefulness of plant observations alone may well be insufficient due to the variation in stress-response physiology among the various genera of wildflowers. Some varieties will show signs of water stress relatively early and before serious damage can occur. For example, Geraldton waxflower adjusts its leaf angle away from the sun and its flowers close-up to reduce heat stress and evaporation, thus reducing water loss. If the water stress is small or limited then the plants will recover with few long-term effects (Akilan et al. 1994a). However, not all plants have developed these traits and growers need to monitor and schedule irrigation to avoid a reduction in yield. Each crop will have different water requirements depending on the plant type or variety, soil type, geographical location, season and climatic conditions, solar radiation intensity, the presence of pathogens, and the volume and quality of water available (Forsberg 1988; Burke and Parlevliet 2002).

The moisture status of plants can also be measured using sap-flow sensors which tend to be used for research purposes (Akilan et al. 1994c; Akilan et al. 1995). Other technologies for monitoring plant
water status include infrared guns (used in the cotton industry) and pressurised chambers which measure leaf water potential. The technology behind such devices is becoming cheaper, bringing them into the realm of irrigation-scheduling tools, as opposed to purely research-based tools (Qassim and Ashcroft 2006).

**Soil moisture storage and measurement**

One of the most common methods employed by growers is the visual observation and feel of the soil (Qassim and Ashcroft 2006). A more accurate method is to use soil moisture sensors. There are several styles and types of sensors that can be used. A sensor should be chosen to suit the soil type, plant variety, cost and usability. Correctly installed sensors can provide actual soil moisture readings instantly and allow more accurate calculation of irrigation requirements by letting the grower know how much water is stored in the soil profile; through a knowledge of soil type, this can indicate the quantity of water available for plant use. Soil moisture measurements also provide the grower with information regarding the depth at which the plant is able to extract water and indicates periods of high water use which may be correlated to growth stages. However, they do require some technical understanding of their operation and maintenance. Some require more maintenance than others, but once installed correctly they only need minimal maintenance. The benefits of using a sensor system can outweigh the cost and labour involved.

Unfortunately a discussion on soil moisture sensors and their capabilities is outside the scope of this review. It is strongly advised that farmers consult a specialist to help determine the correct type of sensor to use; otherwise, considerable money could be spent setting up a system that may not provide the required information. For further reading regarding soil moisture sensors, see Rolfe et al. (2000), Burke and Parlevliet (2002) and Charlesworth (2005).

Regular and continuous soil moisture monitoring allows determination of the relative changes in soil moisture before, during and after an irrigation event. This information can be further used in making decisions on irrigation management (Qassim and Ashcroft 2006). Soil moisture monitoring is commonly recommended as the best method by which to schedule wildflower irrigation (Reid 1992; Tregea 1994; Growns 1995; Silber et al. 2007) and is claimed to take the guesswork out of when to irrigate (Walker 1999).

**Climatic data: crop factors and crop coefficients**

Determining the crop water requirements by indirect methods is based on estimates of water use as driven by local climatic forces, namely evaporation. Crop water use is generally less than open pan evaporation, and the difference is known as the ‘crop factor’
(a decimal value that relates crop water use at a specific stage of development to the quantity of water evaporating from a free surface) (Qassim and Ashcroft 2006). The quantity of water used is determined by:

\[
\text{Crop water use (mm)} = \text{crop factor} \times \text{evaporation}
\]

Daily evaporation assessment is the less-expensive method and can be a good way to determine irrigation rates. Evaporation rates can be obtained from a local evaporation pan or from data available on the Australian Bureau of Meteorology (BOM) website (www.bom.gov.au). If a farmer has an evaporation pan (Class A) on site that represents the local evaporation rates and it is monitored daily, this method can help to reduce total water use by only applying the amount of moisture that has been lost due to evaporation. If the BOM’s data is used, then the farmer must be aware that these values may not represent specific local climate and evaporation rates and do not take into account any localised weather variations.

Alternatively, a ‘crop coefficient’ relates crop water use at particular development stage to the amount of reference crop evapotranspiration (ET\textsubscript{0}) which can be calculated from collected weather data. The values derived from crop factors and crop coefficients can differ by as much as 30 per cent so it is very important to understand the difference. The easiest way to remember the difference is that crop factors are used with pan evaporation figures, while crop coefficients are used with evapotranspiration (ET\textsubscript{0}) figures (Qassim and Ashcroft 2006).

The use of crop factors or crop coefficients provides a good estimate of how much water the crop needs. Unfortunately, identifying specific crop factors is laborious and expensive, and the process has been conducted for only a few wildflower crops. For a good explanation and examples of calculating irrigation from evaporation figures, refer to Rolfe et al. (2000) and Burke and Parlevliet (2002).

**Wildflower water requirements**

Research into the water use of wildflower crops either involves measuring the changes in Plant Available Water (PAW) from soil moisture sensor data (Silber et al. 2006; Silber et al. 2007), or by direct measurements of sap flow (Akilan et al. 1994c; Akilan et al. 1995).

This review of literature has shown that there is no generic solution when it comes to irrigation scheduling for wildflowers. It is dependent on each variety, as crops from different families or genera will have different water requirements and responses to water stress. While individual research papers are discussed individually, where figures are quoted for crop factors, crop coefficients or simply total water use, they have been summarised in Table A1 to show the range of values that these crops require. It must be stated that the irrigation quantities discussed have been derived for specific varieties in particular geographical locations and soil types that may not be directly transferable to other geographical areas. In the case of Geraldton waxflower, the irrigation quantities presented are for farms in Western Australia growing in free-draining sandy soils. If these irrigation quantities were used without specialist consultation or in an area with heavier soils and a fertigation system, then it is possible that such quantities could adversely affect the crop by inflating soil salinity or by creating a waterlogged soil that could promote root rot and pathogen dispersal (Forsberg 1988).
Research has been conducted into the response of protea hybrid ‘Sylvia’ (Protea susannae x Protea exinia) to varying irrigation regimes in both protected structure and in-field situations in South Africa (Mortimer et al. 2003). In a glasshouse trial, irrigation regimes were manipulated to 20, 40, and 60 per cent of field capacity of a free-draining growing medium, such as sand. It was found that greater water application resulted in an increase in both root and shoot growth, with the maximum growth being at 40 per cent of field capacity. When replicating the trial in-field, irrigation intensities were set to dry-land (no irrigation), normal practices and double irrigation. It was found that the irrigation regime did not influence the vegetative or reproductive growth, but there was a significant difference in soil moisture content of the upper 30 cm of soil and a difference in the development of cluster roots between the irrigation regimes. The dry-land plants (no irrigation) had a more extensive and deeper root system that penetrated below 1 m, while plants under supplemental irrigation had greater growth of cluster roots within the upper 30 cm of soil. The researchers concluded that although the dual root system allowed established plants to access moisture from further down the profile, it is still important to maintain cluster root growth near the surface for nutrient uptake. It was advised that growers should consider this when developing crop management practices (Mortimer et al. 2003).

The results from Mortimer et al. (2003) were supported by the work of Silber et al. (2006, 2007) who investigated the effects of deficit irrigation on Leucadendron ‘Safari Sunset’ growth. Silber et al. (2006, 2007) showed that various levels of deficit irrigation and fertiliser strategies had a distinct influence on root growth and PAW. Silber et al. (2006) found that the greatest root-length density occurred in the 0 to 60 cm depth zone of the soil profile with a maximum horizontal growth of 20 cm and that root-growth densities followed the wetted area provided by irrigation. They calculated that the average plant root system occupied less than 0.24 m3 of actual soil volume and this was even lower under higher deficit irrigations. There was a significant, indirect effect of deficit irrigation on the soil volume that could support root growth.

Silber et al. (2006) also found that the lowest soil water content was consistently within 25 to 45 cm of the vertical profile, indicating that this zone was the main water-uptake area for the plants. Further analysis revealed a significant linear regression between soil water content and plant fresh weight. Subjecting plants to high levels of water stress resulted in diminished flower head dimensions and poor marketable quality, while plants under no water stress developed excessive vegetative growth (e.g. stems and branches were too long, and denser foliage growth was discarded at harvest).

The 2007 study by Silber et al. expanded on their earlier work by manipulating irrigation deficits and creating periods of water stress. This showed that stem diameter was an excellent indicator of plant water stress and that irrigation changes were represented in stem diameters within 1 to 2 hours after adjustment. Extensive water stress during the vegetative growth or reproduction phase significantly reduced marketability, stem length and flower size, while short or moderate water stress periods had little or no effect on stem length and flower size but did change leaf dimensions. They highly recommended monitoring plant water stress via stem diameter and/or soil-water tension as an appropriate method of irrigation scheduling, although the
extent and timing of the water stress must be considered. A suggested
guide for deficit irrigation scheduling was to maintain a soil water
content of around 40 per cent of field capacity.

Geraldton waxflower research has shown that these plants have
morphological traits that allow them to tolerate short periods of
water stress without a loss in production. They have been shown to
respond well to increasing irrigation from 25 to 75 per cent of pan
evaporation with an increase in the number of marketable stems from
63 to 89 cm and flower numbers increasing from 61 to 226 per stem
recommended installing a two-line drip irrigation system that could
provide 1 to 20 litres (L) per plant per day; 20 L per day is an extreme
quantity that would only be used in times of high evaporative demand
on free-draining sandy soils. First-year plantings only needed 1 to 2 L
per day, increasing to 4 to 7 L every second day in sandy soils or every
5 to 7 days in heavy soils for subsequent years. Geraldton waxflower
plants have the potential to develop a deep root system that can tap
into ground water if the young roots have not been compromised by
root binding in containers prior to planting. Research has found them
to take most of their water from a depth of approximately 60 cm,
therefore it was suggested that soil moisture sensors (tensiometers or
others) should be used to monitor this depth zone (Tregea 1994; Reid
2003).

Walker (1999), a southern California waxflower grower, provided
values for average water use per plant per week for waxflowers based
upon grower experience. These values are included in the summary
table (Table A1).

The results of a survey conducted by Agwest (Lantzke 1995) to
identify irrigation practices of wildflower farmers in Western Australia
are also included in Table A1. The survey found that crops grown on
soils with a high sand content were irrigated more frequently than
those in heavier soils. Lantzke (1995) also stated that the irrigation
rates varied widely between farms and that many growers were under-
irrigating their crops, particularly where plant densities were high,
which explains the large range of values shown for some of the crops.
He provided Agwest recommendations for irrigation of 1 to 2 L per
plant per day during October to November, 4 to 6 L per plant per day
from December to March, 2 to 4 L per plant per day during April to
May and back to 1 to 2 L per plant per day from June to September.

Many of the projects discussed above have documented plant
responses and production yields relating to irrigation rates, some
showing correlations between plant production and the quantity of
water applied. Each of the researchers discuss consequences such as
aborting flowers, dropping leaves and buds, wilting and ultimately
death, if insufficient water is available. However, managing the crop
and irrigation by monitoring soil moisture content and plant growth
was commonly suggested as a means to avoid losses. Also, a well
designed and installed drip irrigation/fertigation system is preferred
for irrigating wildflowers as it can provide precise water, fertiliser
and chemical application and therefore ensure a superior growing
environment.

The following table (Table A1) summarises all the recommendations
for water requirements, water use estimates and grower experiences in
terms of the quantities of water applied as supplemental irrigation. The
table is separated into the ten diverse plant groups or species grown
## Table A1. Summary of plant water requirements based on grower estimates and published research

<table>
<thead>
<tr>
<th>Reference</th>
<th>Plant</th>
<th>Age /timing</th>
<th>Soil type</th>
<th>Litres / plant/day</th>
<th>Frequency</th>
<th>% of pan evaporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horsman (2004)</td>
<td>Banksia</td>
<td>-</td>
<td></td>
<td>8–12</td>
<td>2–3 per week</td>
<td></td>
</tr>
<tr>
<td>Lantzke (1995)</td>
<td>Banksia</td>
<td>-</td>
<td>Yellow sand</td>
<td>1.5*</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Seaton (1999)</td>
<td>Banksia</td>
<td>-</td>
<td></td>
<td>2–3</td>
<td>daily</td>
<td>40</td>
</tr>
<tr>
<td>Burke and Parlevliet (2002)</td>
<td>Banksia</td>
<td>-</td>
<td></td>
<td>6</td>
<td>daily</td>
<td>40–50</td>
</tr>
<tr>
<td>Burke and Parlevliet (2002)</td>
<td>Boronia</td>
<td>-</td>
<td></td>
<td>13.5</td>
<td>daily</td>
<td>75–100</td>
</tr>
<tr>
<td>Lantzke (1995)</td>
<td>Boronia</td>
<td>-</td>
<td>White sand</td>
<td>1.7–10*</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Seaton (1999)</td>
<td>Boronia</td>
<td>-</td>
<td></td>
<td>2–10</td>
<td>daily</td>
<td>75–100</td>
</tr>
<tr>
<td>Anon (2000)</td>
<td>Christmas Bush</td>
<td>2–3 yr old</td>
<td></td>
<td>4</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Seaton (1999)</td>
<td>Conospermum</td>
<td>-</td>
<td></td>
<td>2–4</td>
<td>daily</td>
<td>50</td>
</tr>
<tr>
<td>Lantzke (1995)</td>
<td>Eucalyptus</td>
<td>-</td>
<td>White sand</td>
<td>1.4*–10</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Lantzke (1995)</td>
<td>Kangaroo paw</td>
<td>-</td>
<td>White sand</td>
<td>1.5*</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Lantzke (1995)</td>
<td>Kangaroo paw</td>
<td>-</td>
<td>Yellow sand</td>
<td>1.58</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Seaton (1999)</td>
<td>Kangaroo paw</td>
<td>-</td>
<td></td>
<td>2–4</td>
<td>daily</td>
<td>50</td>
</tr>
<tr>
<td>Burke and Parlevliet (2002)</td>
<td>Leucadendrons</td>
<td>-</td>
<td></td>
<td>6</td>
<td>daily</td>
<td>40–50</td>
</tr>
<tr>
<td>Barth et al. (1996)</td>
<td>Leucadendrons</td>
<td>-</td>
<td></td>
<td>8–12*</td>
<td>1–2 per week</td>
<td></td>
</tr>
<tr>
<td>Burke and Parlevliet (2002)</td>
<td>Pimelea</td>
<td>-</td>
<td></td>
<td>6</td>
<td>daily</td>
<td>40–50</td>
</tr>
<tr>
<td>Seaton (1999)</td>
<td>Pimelea</td>
<td>-</td>
<td></td>
<td>2–4</td>
<td>daily</td>
<td>50</td>
</tr>
<tr>
<td>Burke and Parlevliet (2002)</td>
<td>Protea</td>
<td>-</td>
<td></td>
<td>6</td>
<td>daily</td>
<td>40–50</td>
</tr>
<tr>
<td>Lantzke (1995)</td>
<td>Protea</td>
<td>-</td>
<td>White sand</td>
<td>10*</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Seaton (1999)</td>
<td>Protea</td>
<td>-</td>
<td></td>
<td>2–12</td>
<td>daily</td>
<td>75–100</td>
</tr>
<tr>
<td>Silber et al. (2007)</td>
<td>Protea</td>
<td>-</td>
<td>maintain 40% field capacity of soil profile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barth et al. (1996)</td>
<td>Protea</td>
<td>-</td>
<td></td>
<td>8–12*</td>
<td>1–2 per week</td>
<td></td>
</tr>
<tr>
<td>Lantzke (1995)</td>
<td>Schoitzia</td>
<td>-</td>
<td>White sand</td>
<td>10*</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Seaton (1999)</td>
<td>Tea tree</td>
<td>-</td>
<td></td>
<td>2–6</td>
<td>daily</td>
<td>75</td>
</tr>
<tr>
<td>Lantzke (1995)</td>
<td>Vericordia</td>
<td>-</td>
<td>Lateritic gravelly sand over clay</td>
<td>12*</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Burke and Parlevliet (2002)</td>
<td>Waxflower</td>
<td>-</td>
<td></td>
<td>10.1</td>
<td>daily</td>
<td>75</td>
</tr>
<tr>
<td>Considine and Growns (1998)</td>
<td>Waxflower</td>
<td>-</td>
<td></td>
<td>&gt;75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growns (1995)</td>
<td>Waxflower</td>
<td>early summer</td>
<td></td>
<td>4–6</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Growns (1995)</td>
<td>Waxflower</td>
<td>late summer</td>
<td></td>
<td>8–10</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Lantzke (1995)</td>
<td>Waxflower</td>
<td>-</td>
<td>Yellow sand</td>
<td>1.5*</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Reid (1992)</td>
<td>Waxflower</td>
<td>-</td>
<td></td>
<td>30</td>
<td>daily</td>
<td>100</td>
</tr>
<tr>
<td>Seaton (1999)</td>
<td>Waxflower</td>
<td>-</td>
<td></td>
<td>6–10</td>
<td>daily</td>
<td>75–100</td>
</tr>
<tr>
<td>Treges (1994)</td>
<td>Waxflower</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walker (1999)</td>
<td>Waxflower</td>
<td>0–1 yr old</td>
<td></td>
<td>3.8–7.6#</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Walker (1999)</td>
<td>Waxflower</td>
<td>3yrs +</td>
<td></td>
<td>11.4–22.7#</td>
<td>daily</td>
<td></td>
</tr>
</tbody>
</table>

*Supp. irrigation not total water use.

# Original volumes in gallons were converted to litres.
for flower production in Australia and also includes international experiences. Of all the research documented it is apparent that the major focus has been waxflower, both in Western Australia and internationally. The flowers which have been the major focus of this project have received minimal attention, as can be seen by the fact that only one group has provided any information for Christmas bush irrigation, while Proteaceae has been the focus of several researchers both here and overseas.

Factors affecting plant water requirements

Soil and site
As discussed, the frequency of irrigation events will vary depending upon the soil's ability to absorb and retain moisture throughout the profile (Lantzke 1995). Less frequent irrigation is preferable due to evaporative losses that occur both during the irrigation event and from the wet soil surface. Once the soil surface dries, evaporative losses are significantly reduced; however, the plant roots are still able to access moisture from deeper in the profile (Childs 1969). However, the success of production also depends upon the specific plant adaptations and tolerances to different soil conditions.

Site and soil have a significant impact upon the rate at which wildflowers transpire. Many of the researchers have found that wildflowers generally prefer a well-drained soil, such as deep sands, sandy loams or highly structured red clay soils such as volcanic krasnozem soils. More specifically, they have been found to grow best in a light, sandy, well-drained soil with a pH less than 7 and no impermeable layer, such as rocks or heavy clay within 1 m of the surface. However, some South African research discusses species that can grow in boggy or alkaline (pH 7 to 8.5) situations provided there is a relatively constant water flow through the soil (Vogts 1989). Soil salinity is another issue that must be considered. Although several species can grow in slightly saline soils, it is not recommended to plant crops in areas with a soil salinity greater than 10 mS/m (Seaton 1999).

Studies by Silber et al. (2006; 2007) revealed that *Leucadendron* species grew well and provided good flower yields in soils with pH as low as 5. Maier et al. (1995) and Barth et al. (1996) stated that *Protea* cv. ‘Pink Ice’ had higher yields at a site with acidic soil (63 stems per plant per year on average) than at two other sites with a neutral soil profile, (39 stems and 57 stems per plant per year on average). However, soil nutrient tests comparing nitrogen and carbon contents suggested that the acid soil was highly fertile, whereas the other sites were infertile and moderately fertile respectively.

Barth et al. (1996) stated that the duration of the harvest period for *Protea* cv. ‘Pink Ice’ can be influenced by soil fertility and crop nutrient management, which would have a significant impact upon the duration with which supplemental irrigation would be required. Crops that were fully harvested within 6 weeks displayed growth stresses due to poor soil nutrition as opposed to those harvested over 3 months. The authors suggested that soil tests should be conducted to identify any nutrient deficiencies in the soil. It is further claimed that commercially grown *Protea* cv. ‘Pink Ice’ should yield 50 to 65 stems per plant per year with stem lengths greater than 50 cm, while *Leucadendron* cv. ‘Silvan Red’ should produce 250 to 300 stems per plant per year.
Although some protea species have adapted to growing in soils with a proportion of red or yellow clay, they must have a free-draining sub-soil to survive. Vogts (1989) stated that “no protea will grow” in soils with a clay content greater than 20 per cent, a high nutrient content and free salts. The ideal soil for most proteas is a sand or sandy loam with a pH between 5 to 6 and free-draining sub-soil (Vogts 1989; Webb 2007).

If proteas are grown in climates that have different rainfall patterns to that of their original habitat, irrigation schedules should simulate that of the original rainfall pattern. That is, if the variety comes from an area that predominantly has winter rainfall but is grown in an area that has summer rainfall, then winter irrigations should be maintained as well. This will ensure that the growth cycle of the plant is maintained and will enhance the production capability of the plant.

These studies showed that harvest quantity and duration is closely related to soil fertility, water availability and nutrient concentrations. Seaton (2004) and Carson et al. (2000) stated that site preparation is of major importance and can determine the success of a wildflower farm. The recommendations from both authors are that farmers should ensure the site is free of weeds and disease and should conduct a soil survey well before planting. Test holes need to be dug to determine soil type, structure and the presence of any sub-soil constraints that could impact on plant survival. As a general rule, there should be at least 1 m of free-draining soil above any impervious sub-soil layer, but the presence of extractable water in the form of a water table, gravel lenses or other aquifers lower than 1 m are beneficial as they provide an alternative water source during dry times.

Currently, it is understood that Christmas bush grows best in sandy loams or organic sands, preferring a moist, well-drained soil, but is believed to grow in most soil types with a pH of 5 to 6 as long as there is sufficient drainage and an open, sunny aspect and a permanent water supply.

Christmas bush has been found to survive in temperatures as low as –4oC. Growers have stated that plants have survived frosts at –2oC but they suspect anything below –4oC could be dangerous to the plant (Albery, undated). It is grown across several climatic regions with successes and failures within each region. There is little evidence currently as to the preferred growing climate of the plants, but they have been growing and bush harvested in the Sydney area for over a century.

**Slope and aspect**

A land slope of less than 15 per cent is desirable with plantings following the contours of the land to reduce erosion; otherwise, expensive erosion-mitigation work may be needed. However, a slope will assist in excess surface water runoff in high rainfall areas and can help reduce soil-borne disease problems. Planting on a slope, particularly in colder climates, allows cold air to channel down the slope, reducing the severity of frosts. Steeper slopes and extremely steep slopes present other logistical issues when it comes to crop maintenance and harvesting. Access for tractors, spray carts and harvesting equipment can be restricted by steep slopes as well as creating workplace health and safety issues for staff during harvesting. Also, steep slopes can cause irrigation to flow off the area before infiltration can occur (Carson et al. 2000; Seaton 2004).
The aspect of the area can influence plant growth and flower development and ideally the site should have a north-facing slope with plant rows orientated north to south. In areas with a risk of waterlogging, mounded rows may be needed (Seaton 2004). In general, and particularly in south-east Queensland, a north or east-facing slope will provide warmth and protection from cooler south-east to south-west winds in the winter months. A west-facing slope will have strong, cold, westerly winds in winter and hot temperatures in summer, while a south-facing slope will be colder and subject to the prevailing winds (Carson et al. 2000). If purchasing a parcel of land to set up a flower farm, Carson et al. (2000) suggested purchasing the land to suit the crop to be grown, but if the land is already owned then the choice of crop to plant should be decided by the physical and environmental factors of the land, rather than trying to alter the land to suit the crop as this could be an expensive exercise.

**Plant life cycle**

Plants will have different water requirements depending on the stage of their life cycle. Newly established plantings tend to have low water use due to limited leaf area and shallow root systems. However, more frequent irrigations are required during establishment to ensure surface soil moisture is adequate to supply the water for a shallow root system. As the plants mature and leaf surface area and evapotranspiration increases, so too will water requirements, hence an increase in irrigation is needed to balance this water loss (Seaton 1999). These growth phases are taken into account in the summary table (Table A1).

During vegetative growth, plants have a higher water requirement per unit leaf area, than when in a reproductive stage. However, as first buds develop the plant is at its maximum leaf area, hence water requirements are high (Seaton 1999). Silber et al. (2006) found that there was a direct relationship between irrigation practices and vegetative growth. In the first and second year after planting, vegetative growth had a linear relationship with water availability, suggesting that a young plant’s growth is directly proportional to the volume of water applied and that in the early growth phase, water is the major limiting factor for growth. This relationship was found to decline as the plants reached maturity. They surmised that by the fourth year after planting, competition pressures (e.g. light and water availability) became the major influencing factors as the gap between plants is reduced.

Seaton (1999) provided a guide for water usage of cultivated wildflower crops (included in Table A1) and stated that these were only an estimate. Water requirements must be determined to suit each species and are dependent on the plant’s life cycle stage; that is, whether the plant is currently flowering, growing or is in a dormant state. Restricting irrigation during times of flowering, especially in summer when evaporation is at its highest, can have devastating effects on yield, causing stems to wilt and leading to flower abortion. He also stated that the growth form of the plant needs to be considered when scheduling irrigation. Species with shallow root structures that rely on extracting water from close to the soil surface will require more frequent irrigations to combat evaporation. Plants with deep root systems can extract deeper ground water and survive with less frequent but deeper irrigations. For example, boronia can require three irrigations per day due to their shallow root system, while established
banksia plants have a deep root system that is not as affected during times of high evaporation.

Research conducted by Barth et al. (1996), Maier et al. (1995) and Silber et al. (2006, 2007) showed that stem elongation should start in early spring and continue until October when stem growth starts to decline. They found that stem elongation during the peak growth period was, on average, around 119 mm per month. Some crops will experience a second growth flush between November to February depending on the soil fertility and available water, but all growth ceases around April. Dupee and Goodwin (1992) reported that peak vegetative and reproductive growth in *Protea neriifolia* ‘Salmon Pink’ in south-east New South Wales was in the period of January to February, suggesting that, not only does growth period vary between cultivars of the same genera, but it is strongly influenced by geographical location, climatic conditions, and the availability of nutrients and water.

**Water quality**

Water quality is another important factor that needs to be considered, especially if recycling or re-using wastewater. There may be plenty of water for irrigation but if the quality of that water is poor it will affect plant development. In some cases, poor water quality can kill all plants and render the soil useless. Water sources, particularly on farms that have been previously cultivated, need to be tested for chemical residues and the presence of pathogens such as *Phytophthora*. Not only can chemical residues, such as herbicides, kill plants directly but over time they can slowly increase concentrations in the soil that can inhibit plant development or growth. Water sources that have pathogens can re-infect areas that have been disinfected (Beardsell et al. 1996; Dunne 2001, 2002; Carson et al. 2000). There are many diseases that can affect wildflowers and be transmitted/transferred via irrigation water or carried by staff and equipment. In some flower farms of Western Australia, 50 per cent of the crop has been lost due to *Phytophthora* infections that were not controlled (Dunne et al. 2003).

High levels of chlorine (used for disinfestation) in irrigation water can increase soil salinity over time or burn plant tissues if high concentrations are used. Seaton (1999) and Carson et al. (2000) suggested chlorine content for irrigation water should not exceed 220 parts per million (ppm) (220 mg/L) or an electroconductivity (EC) of 0.65 millisiemens per centimetre (mS/cm) to avoid affecting the plants. If using a fertigation system and water is disinfected with chlorine, the reaction of chlorine salts must be factored in when determining fertiliser concentrations. Chlorine in irrigation water will quickly react with iron, manganese, ammonium ions and other organic compounds before the chlorine has time to kill pathogens or before the nutrients can be taken up by the plant (Beardsell et al. 1996; Rolfe et al. 2000). These reactions can also alter the pH of the water and hence affect the pH of the soil. However, through monitoring water quality and testing the soil, growers can specifically target fertiliser concentrations to suit their crop (Beardsell et al. 1996).

Previous studies have suggested that members of the Proteaceae family may be moderately salt tolerant. A study by Walters (1991) found that certain *Protea* species were not adversely affected by irrigation water with an EC of 3.1 dS/m (approximately 1700 ppm). However, as Reid (2003) pointed out, the Walters (1991) study investigated the vegetative growth of 2-year-old plants and not
flower yield or stem length. Reid compared tissue test results of some Australian natives with the Walters (1991) study results and could not identify a significant difference in salt accumulation between the plants and as a result was wary of the suggestion that these plants are moderately salt tolerant.

Rodriguez-Perez et al. (2000) reported safe irrigation water and soil extract EC values for *Protea obtusifolia* of 2.7 and 6.0 dS/m respectively, and a reduction in vegetative growth of approximately 21 per cent for each unit increase in EC above those thresholds. Their later work (Rodriguez-Perez et al. 2001) researched the effects of increasing salinity due to fertigation on *Leucospermum cordifolium*. It was found that after 9 months the plants fertigated at 1.5 dS/m showed minor signs of salt effect, 2.5 dS/m caused significant foliage damage and 4.2 dS/m or above caused plant death. They also found a distinct correlation between increasing salinity in the soil and an increase in leaf salt concentrations. Plant growth also decreased proportionally with an increase in salinity. However, the authors pointed out that different quantities and combination of fertiliser could have a synergistic or antagonistic effect depending on the fertiliser ratios, plant variety, irrigation quantities and existing nutrients in the soil.

Although proteas are considered drought and slightly salt tolerant by some, Vogts (1989) pointed out that all proteas are capable of surviving with limited water but need large amounts of water to return high yields and leach salts from the root zone. When developing irrigation strategies, then, it is important to consider the source of the water. Where salts are present, a fraction of applied water must leach beyond the root zone to ensure salts do not accumulate and reach toxic levels within the soil profile.

Christmas bush is intolerant of salty water; similarly it does not like hot dry or salty winds, which can cause flower drop, affecting either a few stems or the entire plant. Indeed such winds can cause permanent injury to the plant, therefore wind breaks or wind diversion shelters are advised for locations that are effected by strong hot winds (Worrall and Dalley 1998; Freeman and Mills 1999; Zorin et al. 2000; Zorin et al. 2001).

**Management practices**

Management practices will have an influence on plant water demand and consequent irrigation scheduling. Crops grown in high density rows have increased competition for available resources (e.g. water) and so irrigation frequency will need to be increased to provide sufficient water to maintain growth of all plants. Conversely, crops grown in low densities with open spaces or bare soil between plants will suffer from high rates of evaporation. Also, open row plantings provide space and resources for weed growth, which can increase the loss of moisture from the soil via evapotranspiration. One method used to reduce soil moisture loss is mulching over bare soils and weeds or growing a shallow-rooted ground cover in the inter-row spaces. Plastic mulch or weed matting is best for plants that prefer slightly acidic soils; standard mulches tend to change the soil pH as they break down and plants such as *Protea* species that are sensitive to pH changes can be adversely affected (Vogts 1989; Seaton 1999).

Other studies have suggested that management practices as well as nutrient availability have a major influence on flower production. Gerber et al. (2001b) presented results on the impact of pruning on
bud initiation of *Protea* cv. ‘Lady Di’. They found that defoliating a plant prior to spring growth will have an adverse effect by stopping bud initiation or causing the abortion of any early buds. They suspected that the carbohydrate stored in winter leaves is used for bud development. If these leaves are removed prior to or during bud development, the plant will abort bud initiation until new leaves are fully extended. An additional study (Gerber et al. 2001a) found that pruning in the winter months of one year can improve the harvest in the following years, but is also dependent on the temperature of early spring. For further discussions on pruning refer to Gerber et al. (2001a; 2001b).

Some wildflower crops have an advantage over other plant types in that they will produce proteoid roots when grown on impoverished soils. These roots re-grow each year during growth flushes and increase the uptake of nutrients. However, their formation and longevity is also related to soil moisture levels. If soil moisture and nutrient concentrations are consistently high and readily available for plant growth, then proteoid roots will die off and only reform if moisture or nutrient levels become low again. Proteoid roots have been found growing in situations where moisture levels are sufficient but certain nutrients are in limited supply. Conversely, they also have been found growing in situations where nutrients are not limited but moisture levels are low. They are mainly limited to an area approximately the size of the plant canopy and are believed to have been developed to capture and re-absorb the nutrients lost via leaf drop. They are very sensitive to disturbance and soil pathogens; therefore, any soil maintenance should be carried out during the winter months when the plants are in a dormant state (Lamont 1977).

Mulching around plants is a good idea to reduce soil moisture loss via evaporation or weed growth, but care must be taken not to damage the stem base or expose the proteoid roots in the process. However, standard mulches, when decomposing, can alter the nutrient balance and acidity of the soil. This could adversely affect the development of seedling proteoid roots and hence the future productivity of the plant. To avoid this possibility it is suggested that plastic mulch, preferably in a single sheet, be used directly under the plant (Vogts 1989).

Application of a mulch layer and regular monitoring of the soil moisture, particularly during the establishment stage, should be conducted to ensure a balance between active root growth and reduction of water stress. Silber et al. (2006, 2007) found that the first two years after planting *Leucadendron* cv. ‘Safari Sunset’ is the period when soil moisture monitoring and specific irrigation scheduling is most important. They found that when seedlings were planted in rows 1.93 metres (m) apart and at 80 cm between plants in the row (plant densities = 0.62 plants per m²), the area between plants dried out quickly and water was the only limiting factor during this growth phase. Irrigation was provided by two drip lines with emitters at 40 cm separation, one line on either side of the plant approximately 20 cm apart, which supplied 1.6 L per hour. This provided a wetted area of approximately 0.24 m² and was sufficient to stimulate root growth. When the irrigation rate was reduced they found there was a corresponding reduction in root growth activity.

Choosing an appropriate planting density and irrigation system is paramount for healthy, productive growth and should be done considering the crop variety, growth form and the physical properties
of the land. Plants that experienced greater competition stresses from more dense plantings or were unpruned were found to produce more second-rate flowers than those pruned or in less dense plantings. Furthermore, temperatures that were higher or lower than those of the plants’ natural habitat affected bud initiation. It was stated that manipulating day length will allow growers to advance or retard bud initiation and determine harvest times (Fuss and Sedgley 1991).

Major influences on growth in banksia flower production were attributed to site location and climate. The highest flower yields were from sites that more closely matched the natural habitat and climate of the plant. Management practices were considered the next most influencing factor (Fuss and Sedgley 1991). Percival et al. (2001) found that variations in climate within the same geographical location can have a distinct affect on plant growth and flower production. Variations in temperature and relative humidity in early growth stages have the potential to evaporate moisture from the surface soil layer, causing water stress and reduced growth.

Webb (2007) suggested that land preparation prior to planting can influence the success of a crop and that land should be prepared at least 6 months before planting. All trees, weeds and dead wood should be removed, and then the ground should be deeply tilled. Equipment needs to be thoroughly cleaned of old soil beforehand to avoid transference of soil pathogens. A project initiated in May 1999 by AgWest on the sudden death syndrome focused on soil fauna as the cause of plant deaths and reported that once an area was affected by soil pathogens, they would persist for many years. Growers recorded plant deaths of 20 per cent of the crop in the first year, 20 per cent in the second year and plant losses of 50 per cent in the following years if the affected areas were re-planted. Increasing irrigation frequency and fertiliser did not reduce the death rate (Berney 2000).

Most plantings of Christmas Bush are on mounded rows approximately 3 to 4 m apart, to allow for good light penetration and harvesting equipment, with plants spaced from 1 to 2 m apart. Plants can be spaced at 1 m intervals for the first five to six years but after that competition for resources (e.g. water and light) can interfere with flower production and quality. Some growers will remove every second plant after this initial period, with remaining plants producing for at least 10 years. Planting should be avoided in late spring or summer, as trials have reported significant plant losses at this time due to high soil temperatures. Weed mats or mulches under the plants are recommended to suppress weed growth and limit soil erosion (Worrall and Dalley 1998; Zorin et al. 2000; Zorin et al. 2001).

**Fertiliser**

Barth et al. (1996) stated that for Protea cv. ‘Pink Ice’ harvest length can be influenced by soil fertility and crop nutrient management. Crops harvested in a six-week period as opposed to over 3 months displayed growth stresses due to poor soil nutrition or incorrect irrigation. The authors suggested that soil tests should be conducted to determine nutrient deficiencies and that commercially grown Protea cv. ‘Pink Ice’ should yield 50 to 65 stems per plant per year with stem lengths greater than 50 cm, while Leucadendron cv. ‘Silvan Red’ should produce 250 to 300 stems per plant per year.

Vogts (1989) stated that a typical protea requires very little fertiliser and that phosphorus and potassium fertilisers should be avoided, as
proteas are so efficient at extracting these compounds from the soil that they can poison themselves if there is an excess. She also stated that ammonia-based fertilisers should be used instead of nitrate or nitrite fertilisers and trace elements should be applied sparingly unless flowers are harvested extensively. Furthermore, standard mulches should not be used as they release nitrates as they decay; instead, pine needles and peat or plastic mulches should be used.

Generally, wildflowers have evolved to survive in soils with limited nutrients and have narrower nutrient requirements than other crops. It is difficult to recommend fertiliser regimes for wildflowers generally as each species has specific nutrient requirements and ratios depending on the soil type. Some varieties can tolerate high levels of fertiliser salts if regular irrigations are applied and some varieties are generally intolerant of standard fertilisers with high levels of nitrate and phosphate. Caution is advised when applying standard fertilisers to wildflowers (Vogts 1989).

A study by Silber et al. (2006) found that nutrient levels of the soil directly below a plant did vary depending on fertigation concentration and deficit irrigation scheduling. That is, a high concentration of fertiliser applied under deficit irrigation could lead to an imbalance in electroconductivity (EC) and pH of the soil, creating greater problems. They suggested that soil nutrient concentrations should be monitored and adjusted to suit the irrigation regimes being used and the plants’ growth phase.

Conclusions and recommendations

A question was raised at the beginning of this review: what are the optimum irrigation techniques for key wildflower crops? This has been difficult to determine for each variety in all situations, but many authors have provided information that can be used to help growers determine what is best for their farm. This review has identified that not only should growers consider their irrigation practices in relation to managing wildflower production, but should also assess the irrigation system used for these crops. Inefficient or non-uniform irrigation systems can cause problems by over-watering one area while under-watering another, which will have an impact on production.

The research shows that root development is proportional to the wetted area that an irrigation system provides and is particularly important for young or newly planted crops. However, it is also important to allow the plants to develop root systems outside of the wetted area of an irrigation system so that water stored at lower depths can be accessed during times of drought. If a plant’s water requirements are provided for totally via an irrigation system in the top 45 cm of the soil profile, roots are less likely to develop outside of this zone and in times of limited or no water the plants will experience severe water stress.

Trials have shown that when the plant experiences severe water stress, vegetative growth is diminished, stems are stunted and flowers are aborted. Many wildflowers have evolved to cope with extreme conditions such as water stress and can survive a drought, but yield will be considerably reduced and may take one to two growing seasons before stem length and flower-head size or quality return. If the plants are allowed to develop deep roots in the early stages of growth then the effects of water stress during drought will be reduced and production can rebound more quickly.
Ideally, an irrigation system should be a drip system comprised of two lines laid under mulch with emitters either at 40 or 80 cm separation and should apply 1.6 to 3 L per hour. Irrigation rates are still under investigation, but 2 to 3-year-old plants require about 4 L per day, while mature plants need a moist, well-drained soil. Avoid waterlogging as this can cause root rot and encourage soil pathogens (Worrell and Dalley 1998, Albery undated).

Application rates will depend on the absorption rate of the soil and tests should be conducted to determine infiltration rates. Irrigation frequency will also depend on soil type, moisture-retention capacity and rainfall for the geographical area of the farm, but studies have suggested irrigations should be daily in summer and reduced during winter. However, soil moisture sensors or evaporation values will remove some of the guess work and will help farmers to determine irrigation frequency and duration. Soil moisture sensors such as tensiometers will provide a more accurate guide to scheduling irrigation, but using evaporation rates is a quick method that can be implemented without any financial outlay. If no crop factor is available and evaporation rates are used to schedule irrigation, it is suggested that 40 to 50 per cent of the daily evaporation rate will maintain readily available water for most wildflower crops once the soil is wet.

All of the studies conducted into Protea irrigation and production have discussed the various practices that can affect the quality and yield of flower production, but there is little consensus on what is the optimum or best irrigation practice for these plants. Some suggest an irrigation rate of 2 to 12 L per plant per day; others suggest 10 L per plant per day with irrigation days being reduced during winter periods; while others again suggest winter irrigations should continue if they are grown outside of their original habitat. The quantity of water required to produce quality flowers is dependent on several environmental and physical properties relating to the geographical location of the farm. Unfortunately, the information available for Christmas bush is limited and although there have been several studies into the market potential, production yields and nutrient requirements of this plant, optimal water use has not been explored in depth. Current practices follow those for macadamia nut trees as they grow in similar environments. Further research into water-use requirements is needed and will need to be conducted for different geographical regions and environmental conditions before a full production standard can be developed.

The most important concept to consider is that there is no generic irrigation practice for all plants in all situations and locations. It will be affected by the soil properties, slope and aspect, rainfall and growth phase of the plants. A grower needs to determine how the plants are responding to irrigation and conditions of their specific farm to fine-tune their irrigation practice to suit the requirements of their crop. However, the review of the literature has provided guidelines as to how the plants will respond, in general terms, to certain practices. It is strongly suggested that these systems and practices are used as a guide only and that plants are regularly monitored until an appropriate irrigation practice can be identified for a particular farm and crop.

It is also apparent from the literature that there is considerable variation in plant nutrient requirements between wildflower crops, although several wildflowers may be considered to have similar growth requirements. There is a distinct difference in nutrient
concentration tolerance within the *Protea* genus, and these results may be used as a guide but cannot be taken as actual requirements for other crops with similar traits. The synergistic or antagonistic relationship between fertiliser compounds and the actual plant nutrient requirements are specific to the geographical location, soil type and climatic conditions of each farm.

It is strongly suggested that growers conduct soil and water tests to determine any soil amendments required to specifically address local problems, or seek the assistance of an experienced agronomist to advise on crop management practices. For a good overview of the considerations required, see the chapter by Kevin Seaton on management in *Waxflower Manual – managing waxflower for improved quality and profit* published in 2004 by the Western Australian Department of Agriculture and Food. This publication explains the process of setting up a flower farm and provides technical information relating to irrigation, pruning and other factors needed to manage a crop. Another useful reference is *Should I grow wildflowers?*, Agrilink series QAL 0001 by Cynthia Carson et al. (2000).

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Appendix B. Background information on soil moisture sensors

Regular and continuous soil moisture monitoring allows determination of the relative changes in soil moisture before, during and after an irrigation event. This information can be further used in making decisions on irrigation management (Qassim and Ashcroft 2006). Soil moisture monitoring is commonly recommended as the best method by which to schedule wildflower irrigation (Reid 1992; Tregea 1994; Growns 1995; Silber et al. 2007) and is claimed to take the guesswork out of when to irrigate (Walker 1999).

Soil moisture sensors (SMSs) have proven their worth in broad-acre, in-ground farming for irrigation control and can be adapted for use in wildflower production (Charlesworth 2005; Stirzaker 2006). They provide reasonably accurate soil moisture monitoring and plant water-use information that allows farmers to refine irrigation scheduling to meet plant needs and improve water-use efficiency. There are a variety of soil moisture sensor instruments available (Figure B1), starting at around one hundred dollars for a basic sensor through to several thousands of dollars for more sophisticated and accurate units. The cheaper units tend to be insertion probes for immediate spot checking and monitoring of soil moisture but are limited in the depth to which they can be inserted. The more expensive units tend to be permanently installed within the crop and are capable of interfacing with an irrigation controller to automate irrigation or as an override to shut off irrigation when soil moisture levels are optimal.

However, there are several factors that can affect the accuracy and reliability of soil moisture sensors, e.g. soil type and uniformity, soil salinity, installation and calibration. The decision to use an SMS for irrigation scheduling, whether as a monitoring tool or an automation tool, starts with an assessment of the irrigation system, the irrigation controller, soil type, sensor location and the variety of plants grown. If the irrigation system’s uniformity is poor, an SMS will not improve irrigation scheduling or plant quality as the same inherent problems will exist—a growing area that has either over- or under-watered sections will continue to have over- or under-watered sections. The placement of the SMS will determine irrigation scheduling according to the pre-set soil moisture range for the immediate location due to the small sphere of influence or response area a single sensor can measure. One sensor cannot represent the whole farm unless the irrigation system and soil type/properties are uniform. Several sensors may be needed throughout an irrigation zone to average soil moisture across the zone.

The physical positioning of the sensors within an irrigation zone must also be considered. Studies have shown that increased temperatures and wind activity can affect the outer rows of a growing area. An increase in wind can trigger a plant to increase transpiration, drawing more moisture from the growing media and requiring increased irrigation frequency (Rolfe et al. 2000). If an irrigation event was triggered to compensate for the outer row’s moisture use, plants located in the inner rows may be over-watered (Connellan 2003). With a uniform irrigation system and soil type, these effects could be reduced.

SMSs were developed originally for use in mineral soils; and growers using in-ground production methods would only need to follow the
basic installation and calibration procedure. Growers using organic growing mediums (e.g. coir grow bags) would need to identify which SMS is appropriate for their production methods. Although an SMS will operate and provide soil moisture readings in organic media, the physical water retention properties of organic media vary greatly from those of mineral soils. If a grower wanted to monitor the actual moisture content of the soil/medium (e.g. 20 per cent, 30 per cent etc.), a soil/medium-specific calibration of the SMS would be required to give an accurate, quantitative moisture value (Decagon 2006).

If the farm manager simply wanted to graphically monitor soil moisture trends over a day, week or month, or connect the sensor to a rain switch, a sensor could be used without calibration. This scenario would involve the grower comparing the SMS readings to traditional methods of assessing soil moisture content and developing an understanding of the relationship between the two. Once a comparative relationship is known, trigger points based on observations could be identified. Unfortunately, this method would require ongoing observations for the different seasons or growing periods, and would be somewhat time consuming.

An in-depth discussion on soil moisture sensors and their capabilities is outside the scope of this review. It is strongly advised that farmers consult a specialist to help determine the correct type of sensor to use; otherwise, considerable money could be spent setting up a system that may not provide the required information. For further reading regarding soil moisture sensors, see Rolfe et al. (2000), Burke and Parlevliet (2002) and Charlesworth (2005).
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This handbook has been developed to address the key principles of efficient irrigation, with respect to the wildflower industry. It provides guidelines for establishing effective irrigation of in-ground wildflowers for the cut flower market and provides cut flower producers with tools to understand and manage their irrigation system and requirements. These guidelines offer practical steps for the installation, maintenance and management of irrigation systems in ways that save water, protect water quality and maximise productivity.

It provides information about the establishment and maintenance of irrigation for wildflower cropping and will help the grower to communicate in an informed way with irrigation professionals.

The research was conducted by Agri-Sciences Queensland, Department of Agriculture, Fisheries and Forestry with financial and technical support from the Flower Association of Queensland Incorporated (FAQI).

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