DEPARTMENT OF
PRIMARY INDUSTRIES

Water Management Options

Assisting irrigators with Stream Flow Management Plan implementation

Victoria
The Place To Be

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INTRODUCTION

This report is designed to provide Victorian irrigators in unregulated catchments with an overview of the wide range of water management options available for consideration when deciding what action to take in response to implementation of a Stream Flow Management Plan (SFMP).

The environmental flow provisions and conditions contained within a SFMP will vary significantly from catchment to catchment, as do the scale and types of irrigated agriculture present and the circumstances of individual enterprises. This means the information in this report has to be presented at a generic level. Each section endeavours to provide sufficient information to allow a reasonable assessment of each option, with advice on where to seek additional information for a more detailed assessment of its applicability to individual situations.

Significant investment may be required to realign a current irrigated enterprise with the new conditions on water access contained in a SFMP. Before committing to this investment of resources, it is worth considering the direction in which your industry is moving, what other opportunities might give a better return on your investment and the strategic goals for your farming enterprise (and personal life) in the short and long term. A major consideration in deciding which option or combination of options is most suitable for your enterprise is the level of risk that you are prepared to tolerate.

In responding to the new conditions for irrigation outlined in a SFMP, you will need to make two major decisions. Firstly, is it worth continuing with irrigated agriculture under the new regime, or would changing to a dryland enterprise be more suited to your aspirations and situation. Following from this, if it is worth continuing with irrigated agriculture and you do not want to relocate to an irrigation district with greater levels of water security, what can be done to improve the reliability of your current irrigation water supply. Three approaches to securing your water supply are to determine:

(1) Are alternatives to your current method of accessing irrigation water available?

(2) Is it possible to alter the way you manage your enterprise and utilise irrigation water within your property, to reduce the overall volume of irrigation water you require?

(3) Will an irrigation community approach be more effective for your enterprise than pursuing a series of individual actions?

A representation of this decision making process is shown in **Figure 1**, which also summarises the content of this report.

The report is structured to guide you through this process. It has four main sections, these being:

- Considerations before selecting a water management option
- Water management options to secure water supply
- Water management options to help reduce overall water use
- Options that go beyond farm boundaries

The report concludes with a reference section, which lists the references that contain more information about particular options, arranged in topic areas. Some references may be applicable to more than one topic area, so it is worth looking through the entire list.

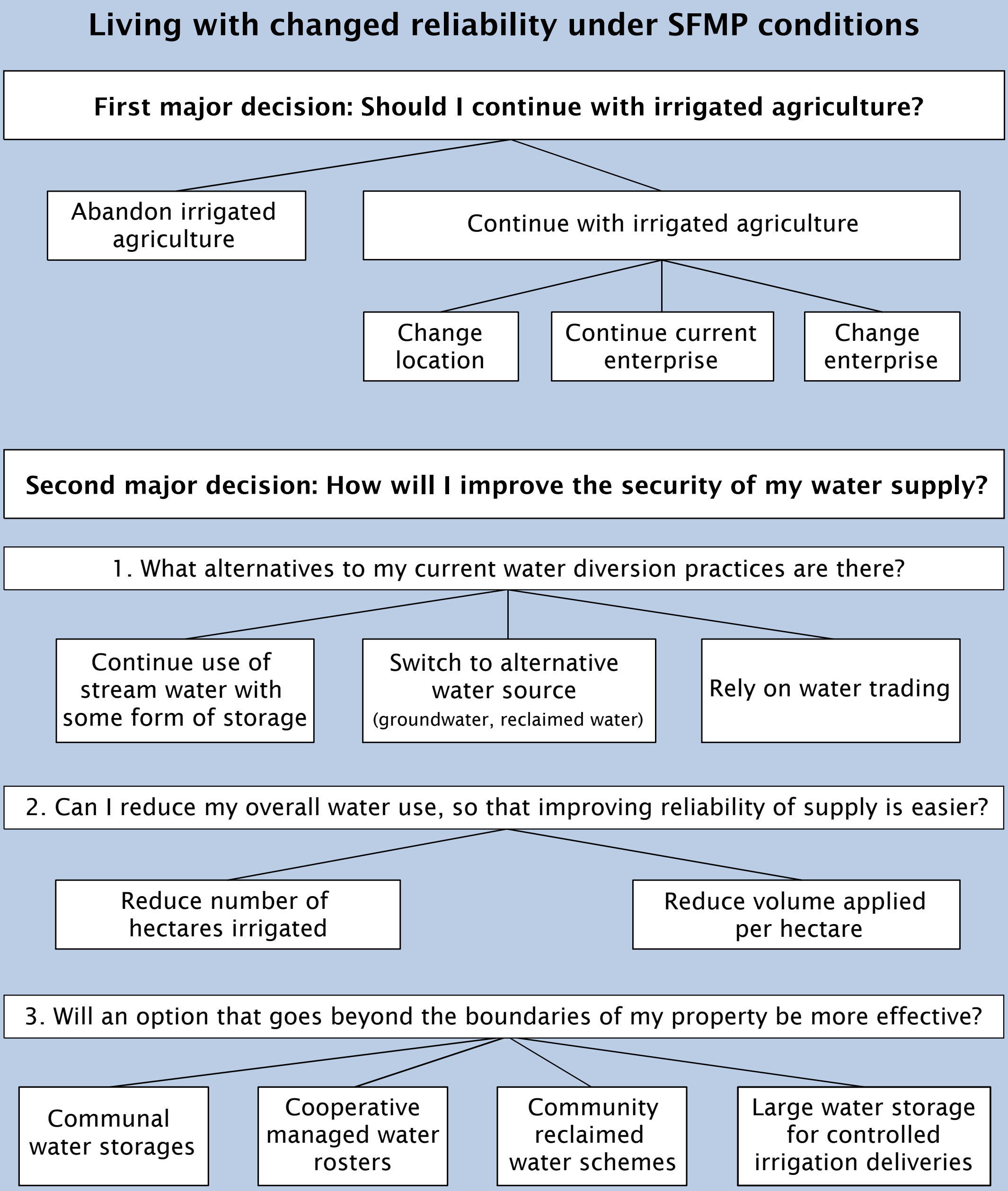

Figure 1: Outline of the decision making process when deciding what actions to take in response to SFMP conditions

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CONSIDERATIONS BEFORE SELECTING A WATER MANAGEMENT OPTION

Significant investment may be required to realign a current irrigated enterprise with the new conditions on water access contained in a Stream Flow Management Plan (SFMP). Before committing to this investment, it is important to consider the long-term directions for your industry and what opportunities may exist in other industries or regions, in order to decide what represents the best investment of resources. The following list of considerations is designed to stimulate thought and is not exhaustive.

Some things to consider:

- What are the likely directions for this industry in the next five, ten, twenty years? Where are prices heading? Is the location of the industry likely to change?
- How does this compare with other irrigated enterprises in this region? Is there a trend away from irrigation?
- What degree of effort will be involved in maintaining a viable irrigated enterprise, now and further into the future? How does this align with your desires in terms of lifestyle and your family?
- Is this enterprise actually impacted by the SFMP? To what degree?
- Given the conditions of the SFMP, your desired lifestyle and land-use trends in this region, is it worth continuing with irrigated agriculture or will a dryland enterprise be more appropriate?
- What level of risk, in terms of access to irrigation water, is tolerable? If security of access to irrigation water is critical to this current enterprise, is relocation to a district with higher levels of water security a sensible move?
- Would changing to a different irrigated enterprise help? What are the water requirements for that enterprise – does it require more or less water, every year or occasionally? What are the trends in that industry in terms of direction and prices?
- In continuing with the current enterprise, should planning be based on current irrigation practices and water use, or is this an opportunity to investigate alternative approaches?
- What impact will my actions have on neighbouring properties or other irrigators? Is it worth forming a water users association to co-ordinate actions in this catchment, if one does not already exist?

From 1st July 2006, all irrigators will be required to have a water use licence, as described by the Victorian Government White Paper *Our Water Our Future* (DSE, 2004). Water use licences are designed to ensure that irrigators are meeting agreed obligations or standards to minimise any adverse side effects on the environment or third parties. All existing irrigators will initially be given a separate water use licence that will allow their existing activities to continue. A new licence will be required if existing operations are redeveloped. For new or re-developed irrigation enterprises, standards close to best practice that prevent adverse side-effects will be required before a water use licence is issued. The water use licence will have ongoing tenure, and apply to all irrigation water used on farm including groundwater. For more detail, please refer to pages 88 – 89 of *Our Water Our Future* (DSE, 2004).

WATER MANAGEMENT OPTIONS TO SECURE WATER SUPPLY

The most appropriate on-farm option or combination of options to secure water supply will depend on your situation, considering a number of financial, biophysical and social factors, including the level of risk your enterprise is prepared to take.

There are three main approaches to improving security of water supply, these being:

- Use of stream water with some form of storage,
- Use of an alternative source of water, and
- Reliance on water trading.

Each approach has differing levels of risk depending on the specific option that is adopted.

One of the most common options identified by irrigators is to continue to use stream water with some form of storage. There are many interconnected factors to consider when building a water storage, as outlined in **Figure 2**. These are addressed in more detail in the section "Use of stream water with some form of storage" **(page 9)**.

Another popular option is to switch to an alternative water source. Before switching to an alternative source of water, you need to be satisfied that a reliable and adequate supply is available. A process for assessing this is shown in **Figure 3**. Two alternatives to stream water are the use of groundwater **(page 13)** and treated wastewater **(page 19)**.

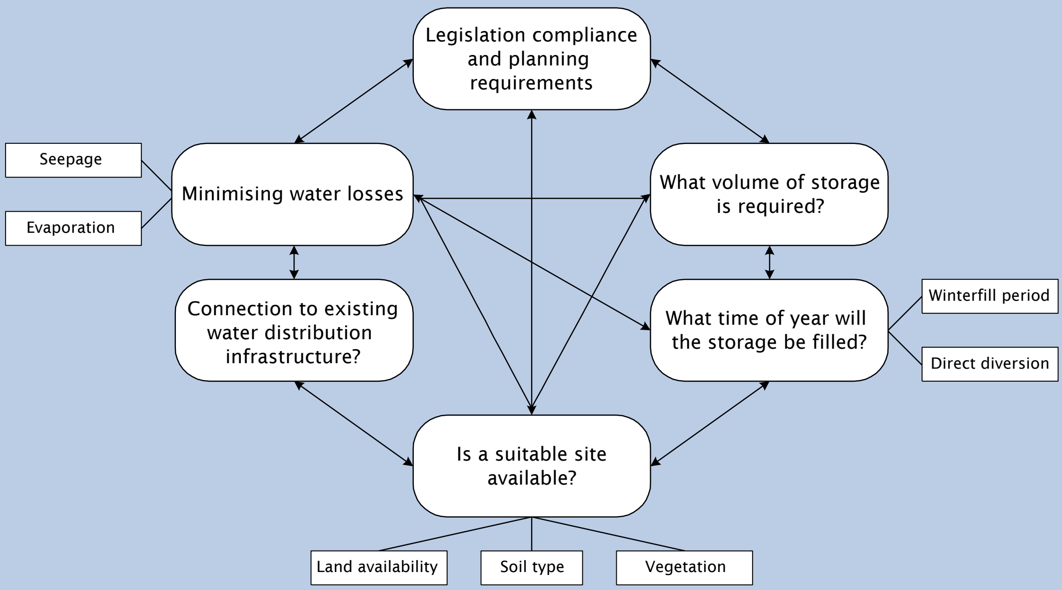

Figure 2: Factors to consider when building a water storage

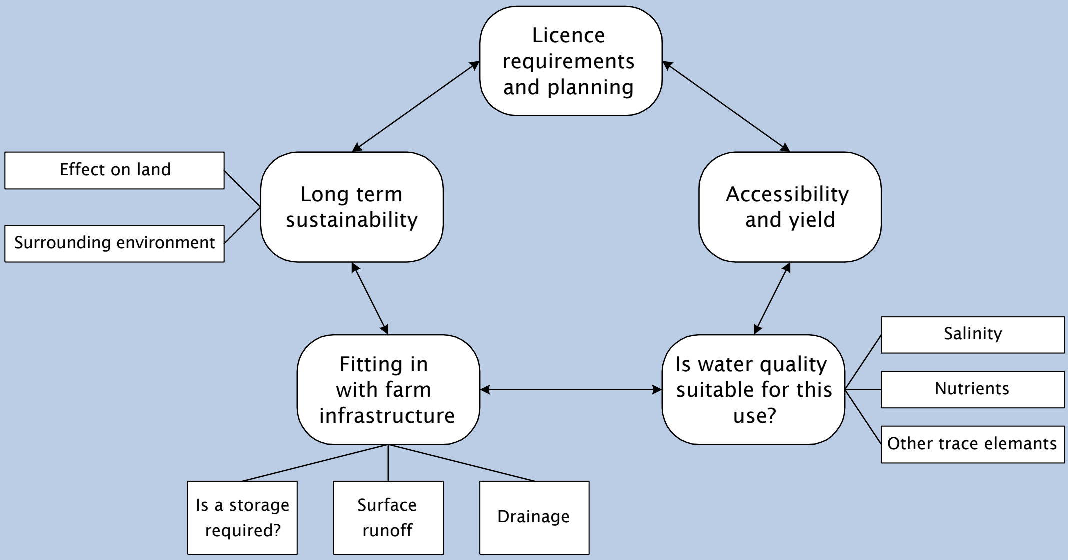

Figure 3: Considerations for assessing the availability of a reliable, adequate supply of water from an alternative source

Use of stream water with some form of storage

When contemplating building a water storage, you should consider:

- what volume storage is required
- is a suitable site available
- what time of year will the storage fill
- how will the storage connect with current water infrastructure on the farm
- how can water losses from the storage be minimised
- what regulations apply to building storages in the area

What volume storage is required?

Storage sizing should firstly consider the water requirements of the enterprise concerned. Water requirements will vary depending on the crop type, geographical location, level of intensity of production, and also change with time depending on seasonal climate factors. Storage size will directly affect the cost of the storage, and also the level of risk an enterprise may face. For example, a large storage with capacity for full or greater than one year's full entitlement will significantly reduce the risk of having an inadequate supply of water during extreme dry periods, provided it is able to be filled. However, it is likely to involve significant construction costs. It may be more appropriate in some situations to build a storage of lower capacity (ie less than full entitlement) at a lower capital cost and live with a higher risk of running out of water in extreme years. It is also worth considering whether the volume of storage required could be reduced by reducing overall levels of water use.

Is a suitable site available?

Construction of a storage may be constrained by the lack of a suitable site. Some properties may currently be fully developed, or plans may exist to expand production in the near future, such that a large area of empty space may not be available. Other properties may have undeveloped areas that are covered by remnant vegetation, so that storage construction will be subject to vegetation clearance regulations.

One of the main factors controlling site suitability will be the soil type present and the slope at the site. The storage needs to be structurally sound and able to hold water, so the soil will need to be structurally stable under the anticipated conditions, and reasonably impermeable. Samples of soil from the proposed dam site, taken to the likely depths of excavation, should be professionally tested prior to further design or construction work. A non-permeable core may be required if there is insufficient suitable material available at the excavation area to build an embankment that will behave uniformly in terms of infiltration or seepage. In these cases, a core of material such as clay is used to provide the impermeable barrier, with the balance of material in the embankment providing structural stability. The core can be located between more permeable material or it may be constructed at either the water or non-water face.

What time of year will the storage fill?

Many conditions of SFMPs relate to direct diversions during summer low flow periods, though there may also be concern about removal of water from the stream system during the winter high flow period. The SFMP conditions will drive available options in terms of when the planned storage may be filled. While converting to a winterfill licence may appear to offer greater security, there will be some years when water is unavailable during the prescribed period. In some catchments the system may already be overcommitted for the winter flow period. If the storage is filled several months before the water is required for irrigation purposes, there is also increased opportunity for water loss through evaporation or seepage in the intervening period. Use of a direct fill licence may offer greater flexibility to respond to high flow events outside the months of June to October, reducing the opportunity for water loss.

How will the storage connect with current water infrastructure on the farm?

It is important to consider how the storage will be linked with the existing water infrastructure on the property. Ideally it should be sited to maximise the use of gravity to distribute water, and minimise the need for double pumping. Factors to consider include the pressure requirements for the current irrigation system, pipe sizing and pump sizing. A complete overhaul of the current water distribution system may be justified to maximise the benefits of the new storage.

How can water losses from the storage be minimised?

All water storages lose some water over time, through a combination of seepage and evaporation. In designing a storage, allowance must be made for these potential losses. However, storages may also leak because of poor construction. Common causes of leaky dams include:

- The work of a contractor unfamiliar with farm dam construction
- Use of an unsuitable soil type in the dam wall
- Poor soil compaction
- Failure to remove topsoil and vegetation at the embankment site
- Failure to backfill exposed rock, gravel or sand in the storage basin
- Failure to construct a cut-off trench
- Poor maintenance of the dam.

Use of a qualified earthmoving contractor with a good record in dam construction may help avoid the creation of a leaky storage.

Minimising evaporation losses

Evaporation from a storage is not constant, varying with location and season. Evaporation losses are generally higher inland than near the coast. This is illustrated in **Table 1**, which gives a rough estimate of the likely evaporation from farm dams for various locations around Victoria, at different times of the year.

Evaporation from a water storage may be reduced by:

- Increasing dam depth
- Minimising water surface area
- Reducing air flows across the water surface
- Strategic planting of native vegetation to provide shade and alter wind movements

Table 1: Average annual and monthly evaporation at different locations in Victoria

	Average evaporation* in millimetres (mm)						
	Annual	January	March	May	July	September	November
Bairnsdale	1229	190	129	52	40	94	157
Ballarat	1309	202	136	47	41	78	155
Bendigo	1559	249	171	52	39	88	192
Coldstream	1257	191	134	47	39	80	145
Hamilton	1325	203	149	49	41	81	150
Horsham	1607	263	180	52	36	90	193
Latrobe Valley	1223	177	130	48	35	81	148
Mildura	1824	286	193	61	42	112	229
Myrtleford	1553	254	175	57	47	85	179
Noojee	1169	168	119	44	36	79	142
Omeo	1211	173	118	50	43	85	145
Shepparton	1705	269	186	64	47	99	209
Wangaratta	1657	267	184	62	48	91	199
Warrnambool	1180	171	128	48	39	78	139
Werribee	1406	211	150	52	38	89	169

* Data sourced from Climatic Atlas of Australia – Evapotranspiration (2001). The data shown is the average point potential evapotranspiration, which can be used as a preliminary estimate of evaporation from a small water body (Wang *et al* 2001).

Other more elaborate approaches to reduce dam evaporation include:

- Use of floating covers
- Use of shade cloth structures
- Use of chemical additives to alter conditions at the water surface

These measures are not suited to all conditions, and may not be economically viable for certain enterprises. Detailed investigation is advised before adopting one on your property. The techniques are currently being tested in Queensland by the National Centre for Engineering in Agriculture – see http://www.ncea.org.au/Irrigation/Page_Projects.html for details.

Minimising seepage losses

There are several ways to minimise seepage losses from a storage (Yiasoumi 2000).

These include:

- Clay lining
- Use of bentonite
- Chemical treatment of soil
- Installing a commercial liner
- Application of a sprayed membrane

Clay lining, particularly using suitable local clay, can be a cost effective way of minimising seepage loss. A minimum depth of 300mm compacted clay should be used. The clay should be placed and compacted in layers, at an optimum soil moisture content. If the clay is too dry, there is potential for air voids to form, making the surface permeable. Compaction can also be affected if the clay is too wet. It is important to maintain a grass and topsoil cover over clay on a storage's embankment and spillway. Topsoil will protect clay soils from drying and cracking, while a grass cover will protect the surface from erosion.

Bentonite is a naturally occurring clay that when wet swells to a volume much greater than its dry volume. It is recommended to determine the rate and method of application of bentonite following laboratory analysis of the soil (Crouch *et al* 1991). It can either be mixed with the surface soil, or applied as an even cover and then buried with site soil, depending on the soil types present. Bentonite may also be spread over the water surface in a full storage, however this method of application is less reliable and should only be used as a last resort.

Chemical treatment of soil, such as the application of gypsum to stabilise dispersive soils, or the use of sodium tripolyphosphate (STPP) to assist in compaction of stable porous clays, can be effective in sealing soil surfaces provided the soil meets certain criteria. Soils should be professionally tested before using a chemical treatment method.

A number of flexible membranes, of differing strength, durability and UV resistance, are available commercially to line storages **(see Table 2)**. For optimal performance, the liner must rest on a well compacted, evenly graded and non-vegetated soil backing that is free of protruding branches and stones. The liner will need to be anchored – this can be done by burying the liner in a trench along the perimeter of the storage.

Table 2: Types of flexible membranes available to line storages

Membrane Type	Uv Degradation	Other Properties
Woven polythene	Very susceptible - short life if not protected by soil. Unlikely to last 5 to 7 years in sun.	Resists tearing. Requires grade < 3:1 to prevent soil slipping off liner.
Black polythene	Susceptible to UV degradation – requires soil cover to prolong life.	Quite thin so susceptible to puncturing. Available in versions using reprocessed resin (weaker) and prime resin. Lasts longer if thicker.
Vinyl (PVC)	Susceptible to UV degradation – requires soil cover to prolong life.	Resists tearing and more flexible than woven polythene.
HDPE, butyl rubber	Does not require protection from sunlight.	Longer life, tougher, and resists tearing. More expensive than polythene or vinyl.
Composite materials (Thin layer of bentonite sandwiched between polypropylene)	Not UV sensitive.	Small ruptures in liner self healed by bentonite. Must be covered with soil for protection from major ruptures.

Sprayed membranes, such as asphalt and concrete, are applied under pressure to the dam surface to provide a continuous skin of non-permeable material. The soil surface needs to be well graded before the application. A thickness of at least 75 mm is required for this approach to be effective, and the seal can be affected by weathering and movement cracks. Sprayed concrete will require steel reinforcement, whereas asphalt does not. Sprayed membranes should be applied by a qualified contractor using specialised equipment.

What regulations apply to building storages in my area?

Construction of an irrigation water storage will need to conform to the requirements of the *Water (Irrigation Farm Dams) Act 2002*. Please contact your rural water authority for specific information about this. The storage will also need to conform with relevant safety standards. Other permits, for example regarding native vegetation management, may need to be obtained from your local council. Please contact the planning department of your local council to find out if there are any special regulations applicable in your area.

Use of an alternative source of water - groundwater

Licence requirements and planning

Like surface water, groundwater use is regulated by the Department of Sustainability and Environment, and managed by rural water authorities. In some areas of Victoria groundwater supplies are considered to be over-allocated, and a moratorium on further extraction of groundwater is in place.

There are 64 Groundwater Management Areas (GMAs) in Victoria, each corresponding to an aquifer within a specified depth range from the surface. A Permissible Annual Volume (PAV) is specified for each GMA, based on the estimated sustainable yield of the aquifer. If the total groundwater allocations in a GMA reach 70% of the permissible annual volume, a Groundwater Supply Protection Area can be declared. Once a Groundwater Supply Protection Area has been published in the government gazette, a Consultative Committee is formed to develop a Groundwater Management Plan for that area. Groundwater Management Plans are similar to SFMPs, specifying rules for the allocation of water, trade in groundwater entitlements, monitoring and metering requirements, and providing for intensive studies of resource availability (NRE, 2002).

Before considering the use of groundwater as an alternative water supply, it is advisable to contact your rural water authority to establish the status of groundwater entitlement and availability in your area, as you will need to obtain a groundwater licence. There is increasing recognition of the interaction between surface water and groundwater systems in the unregulated river systems, so it is possible that future management of both surface water and groundwater will be addressed in streamflow management plans.

Accessibility and yield

Groundwater is commonly accessed by drilling a bore, however in certain locations such as discharge zones, groundwater may be tapped using a pit method (eg draglines, 'improved' springs) or tile drains. Installing a groundwater bore can be complex, expensive and is sometimes described as a 'hit and miss' affair, with no guarantee of tapping into a reliable high yielding aquifer. The cost of installing and operating a bore generally increases with the depth to the target aquifer.

To maximise the likelihood of sinking a reliable groundwater bore, it is recommended to:

- Assess the groundwater potential in your area (contact your water authority, speak to neighbours who use groundwater about its reliability)
- Identify potential sites for bores on your property (perhaps engage a consultant to do this)
- Obtain quotes from potential drilling contractors and contract a driller
- Test the aquifer for yield
- Obtain water samples from the aquifer for water quality analysis, and
- Based on the results of the yield and quality tests, decide on a final site for the bore.

Water quality suitable for use

In 1997 EPA Victoria released the State Environment Protection Policy (Groundwaters of Victoria), which assigned a minimum water quality standard to various 'beneficial use' categories, based on total dissolved solids (TDS) concentrations. TDS is strongly correlated to the electrical conductivity (EC) of a water sample, indicating the salinity of the groundwater. Groundwater is considered to be suitable for irrigation provided the TDS concentration is 3500 mg/L or lower, which is equivalent to an EC of 5.83 dS/m or less. The Department of Sustainability and Environment (DSE) has used these beneficial use guidelines to map the water quality of groundwater resources across Victoria. This will give an initial indication of the suitability of groundwater in your area.

Potential impacts of groundwater quality on your soil

Irrigation water quality can cause unfavourable changes in soil chemistry, leading to soil structural problems and water infiltration problems. Infiltration rates generally increase with increasing salinity, but if the sodium content of the water is high relative to calcium and magnesium, infiltration rates will decrease. In most cases, the potential impact of sodium content will be controlled by water salinity.

Low salinity water (<0.5 dS/m but particularly <0.2 dS/m) tends to leach minerals and salts such as calcium from surface soils, reducing their stabilising influence on soil aggregates and soil structure. Without these minerals and salts, the soil disperses and the dispersed fine particles tend to fill small pore spaces in the soil. This seals the soil surface, greatly reducing the rate at which water can infiltrate the soil, and can also cause surface crusting and crop emergence problems. However, excessive quantities of sodium in the water can have the same effect as low salinity water (promote soil dispersion and structural breakdown) if the amount of sodium exceeds calcium by more than a ratio of 3 to 1. If the magnesium content of the water is greater than calcium, the potential impact of sodium may also be increased. Soil dispersion may also be accelerated if the pH of the irrigation water is too alkaline.

The term 'sodicity hazard' refers to the potential impact of the sodium content of irrigation water on soil structure. The potential hazard is measured by determining the Sodium Adsorption Ratio (SAR, ration of sodium to calcium and magnesium) of the water, or by calculating the Exchangeable Sodium Percentage (ESP) of the soil. Refer to Rengasamy and Walters (1994) for more information.

Potential impacts of groundwater quality on your crop

Plants and crops have different salinity tolerances, so that although the groundwater in your area may be generally considered suitable for irrigation, ie have an EC lower than 5.83 dS/m, it could be too salty for your current crop type and consequently lead to decreased yields. **Table 3** shows reported threshold salinity levels at which crop yield declines, for a range of crop types. If you are using water of a high salinity, it will be necessary to change your irrigation management to ensure adequate leaching of salts from the rootzone.

In addition to salinity, there are other potential impacts on crop performance arising from the groundwater quality. The level of impact varies depending on your particular crop type, and the age of your crop. Juvenile foliage or plants are generally more susceptible to damage arising from poor water quality. Chloride concentrations can be a problem if taken up by roots at levels toxic to the plant, by injuring crop foliage, typically by burning on contact, or by increasing the uptake of cadmium from the soil **(Table 4)**. Excessive levels of sodium can be toxic for the plant, may cause foliage damage, or stunt plant growth **(Table 5)**. Elevated levels of bicarbonate in the water can lead to the precipitation of calcium carbonate. This can result in white scale formation on leaves and fruit, clog irrigation equipment, and in soils may increase the sodium adsorption ratio, which in turn can lead to soil structural problems.

Potential environmental or human health impacts arising from groundwater quality

Other water quality considerations relate to the potential environmental impacts, in terms of contaminating surface water, groundwater or surface soils, or dangers to human health.

The Australian and New Zealand Environment and Conservation Council (ANZECC) and Agricultural Resource Management Council of Australia and New Zealand (ARMCANZ) have set recommended upper limits for concentrations of nitrogen and phosphorus in water used for irrigation **(Table 6)**, based on potential degradation of the surrounding environment. These need to be refined to account for the specific conditions in your area. In some horticultural enterprises, it can be beneficial to have high levels of nitrogen in the irrigation water as it removes the need for additional fertiliser application, however the irrigator would need to ensure that the nutrient rich water was not lost to the surrounding environment.

ANZECC and ARMCANZ have also set upper limits for heavy metal concentrations in irrigation water, based on direct toxicity to plants and the potential environmental or health impact from accumulation of these metal ions **(Table 7)**. The upper limits vary depending on the expected lifetime of the irrigation. For example, if the land is not expected to be irrigated for longer than 20 years, it may be possible to use water with a higher concentration of a particular metal ion, without levels building up excessively in the soil. Conversely, if the land is expected to be irrigated for longer than twenty years, there is greater potential for metals to accumulate in the soil over time, so the upper limit trigger value is set at a lower level.

Table 3: Plant tolerances to salinity of irrigation water – threshold levels at which yield declines (taken from Australia and New Zealand Guidelines for Fresh and Marine Water Quality (2000) Volume 1 Chapter 4).

Common name		Scientific name	Irrigation water EC threshold (dS/m) * for crop growing in:			Average rootzone salinity threshold (dS/m)
			sand	loam	clay	
FRUITS:	Apple	*Malus sylvestris*	2.0	1.2	0.7	1.0
	Avocado	*Persea americana*	2.3	1.3	0.8	1.3
	Grape	*Vitis spp.*	3.3	1.9	1.1	1.5
	Olive	*Olea europaea*	5.1	2.9	1.7	4.0
	Orange	*Citrus sinensis*	2.9	1.7	1.0	1.7
	Peach	*Prunus persica*	4.7	2.7	1.6	3.2
	Rockmelon	*Cucumis melo*	4.6	2.6	1.5	2.2
VEGETABLES:	Bean	*Phaseolus vulgaris*	1.9	1.1	0.6	1.0
	Broccoli	*Brassica oleracea*	4.9	2.8	1.6	2.8
	Carrot	*Daucus carota*	2.2	1.2	0.7	1.0
	Cucumber	*Cucumis sativus*	4.2	2.4	1.4	2.5
	Eggplant	*Solanum melongena*	3.2	1.8	1.1	1.1
	Lettuce	*Lautuca sativa*	2.7	1.5	0.9	1.3
	Onion	*Allium cepa*	2.3	1.3	0.8	1.2
	Pea	*Pisum sativum L.*	3.2	1.8	1.1	2.5
	Pepper	*Capsicum annum*	2.8	1.6	0.9	1.5
	Potato	*Solanum tuberosum*	3.2	1.8	1.1	1.7
	Silverbeet	*Beta vulgaris*	6.5	3.7	2.1	4.0
	Tomato	*Lycopersicon esculentum*	3.5	2.0	1.2	2.3
	Zucchini	*Cucurbita pepo melopepo*	7.3	4.2	2.4	4.7
FIELD CROPS:	Barley	*Hordeum vulgare*	12.6	7.2	4.2	8.0
	Corn (sweet – grain)	*Zea mays*	3.2	1.8	1.1	1.7
	Oats, Soybean	*Avena sativa, Glycine max*	7.0	4.0	2.3	5.0
	Rice	*Oryza sativa*	4.8	2.7	1.6	3.0
	Sorghum	*Sorghum bicolor*	9.4	5.3	3.1	6.8
	Sunflower	*Helianthus annuus*	7.5	4.3	2.5	5.5
	Wheat	*Triticum aestivum*	9.4	5.3	3.1	6.0
PASTURES	Clover, white	*Trifolium repens*	2.5	1.4	0.8	1.0
	Clover, strawberry	*Trifolium fragiferum*	3.3	1.9	1.1	1.6
	Fescue	*Festuca clatior*	7.3	4.2	2.4	3.9
	Lucerne, Hunter River	*Medicago sativa*	4.7	2.7	1.6	2.0
	Phalaris	*Phalaris tubersoa (aquatica)*	5.3	3.0	1.8	4.2
	Tall Wheatgrass	*Agropyron elongatum*	12.5	7.2	4.2	7.5

* Note that irrigation water EC thresholds will depend not only on soil type, but also on the total volume of water applied and leaching fractions adopted in irrigation practice.

Table 4: Chloride concentrations in irrigation water that may increase plant uptake of cadmium from soil, or affect crop foliage (taken from Australia and New Zealand Guidelines for Fresh and Marine Water Quality (2000) Volume 1 Chapter 4).

Chloride concentration (mg/L)	Risk of increasing crop cadmium concentration	Crop sensitivity – risk of foliar injury from contact with irrigation water	
		Sensitivity	Example crops
<175	Low	Sensitive	Almond, apricot, citrus, grape, plum, tobacco
175 - 350	Low	Moderately sensitive	Pepper, potato, tomato
350 - 700	Medium	Moderately tolerant	Barley, cucumber, lucerne, maize, safflower, sorghum
>700	High (if >750)	Tolerant	Cauliflower, cotton, sunflower

Table 5: Sodium concentrations in irrigation water that may affect yield (taken from Australia and New Zealand Guidelines for Fresh and Marine Water Quality (2000) Volume 1 Chapter 4).

RISK OF FOLIAR INJURY (FROM CONTACT WITH IRRIGATION WATER)		
Sodium concentration (mg/L)	**Sensitivity**	**Example crops**
< 115	Sensitive	Almond, apricot, citrus, grape, plum
115 – 230	Moderately sensitive	Pepper, potato, tomato
230 - 460	Moderately tolerant	Barley, cucumber, lucerne, maize, safflower, sesame, sorghum
>460	Tolerant	Cauliflower, cotton, sunflower
YIELD EFFECTS		
Sodium Adsorption Ratio (range)	**Effect**	**Example crops**
2 - 8	Leaf tip burn, leaf scorch	Avocado, citrus, deciduous fruits, nuts
8 - 18	Stunted growth	Beans
18 - 46	Stunted growth, possible sodium toxicity, possible calcium and magnesium deficiency	Clover, oats, rice, tall fescue
46 - 102	Stunted growth	Barley, cotton, lucerne, wheat

Potential impacts of groundwater quality on water infrastructure and your irrigation system

The final aspect of groundwater quality for consideration is its potential impact on your infrastructure and irrigation system.

To limit corrosion and fouling (clogging, encrustation and scaling) of pumps, pipes and other irrigation infrastructure, the water pH should be maintained between 6 and 8.5 for groundwater systems, and between 6 and 9 for surface water systems. There is increased risk of corrosion if the pH is below 6, and increased risk of fouling if the pH is greater than 8.5 or 9. The upper limit pH for groundwater is lower than that for surface water due to increased potential for encrustation and fouling. For spray and drip irrigation systems, filters are required to reduce incidence of blockages.

Fitting in with farm infrastructure

If groundwater yields (flowrates) are too low to meet your irrigation system's requirements, it may be necessary to incorporate a storage into your distribution system and then pump water from the storage. Refer to the section "Using stream water with some form of storage" **(Page 9)** for an outline of things to consider when building a water storage. Depending on the exact groundwater quality, you may also need to install some form of drainage or runoff collection system to ensure low-quality water is not lost to the wider environment.

Long term sustainability

Groundwater usage may not be sustainable due to potential for long term land degradation through salt or heavy metal accumulation, or soil structural decline arising from sodicity. There is a risk of contaminating surface water or other groundwater systems if the water is not managed properly. These considerations are the reason behind many of the water quality limits outlined earlier. In addition to these concerns, groundwater usage can have a direct impact on nearby surface water systems by reducing base flows to rivers, exacerbating low flow conditions (NRE 2002).

Table 6: Recommended upper limits for nitrogen and phosphorus concentrations in irrigation water, to maintain crop yield whilst avoiding bio-clogging of irrigation equipment and off site impacts (taken from Australia and New Zealand Guidelines for Fresh and Marine Water Quality (2000) Volume 1 Chapter 4).

Nutrient	Long term trigger value: Irrigation expected to occur for up to 100 years. (mg/L)	Short term trigger value: Irrigation expected to occur for up to 20 years. (mg/L)	Reason behind trigger value
Nitrogen	5	25 - 125	Minimise risk of contaminating groundwater or surface water. Require specific information on the crop, gaseous losses and locally significant concentrations for environment.
Phosphorus	0.05	0.8 - 12	Minimise risk of algal blooms in the irrigation water.

Table 7: Recommended upper limits for heavy metal concentrations in irrigation water, to minimise build up of contaminants in surface soils and prevent direct toxicity to crops (taken from Australia and New Zealand Guidelines for Fresh and Marine Water Quality (2000) Volume 1 Chapter 4).

Element	Trigger values for irrigation water		Suggested soil cumulative contaminant loading limit* (kg/ha)
	Long term: Irrigation expected to occur for up to 100 years. (mg/L)	Short term: Irrigation expected to occur for up to 20 years. (mg/L)	
Aluminium	5.00	20.00	Not determined
Arsenic	0.10	2.00	20
Beryllium	0.10	0.50	Not determined
Boron	0.50	< 0.5 – 15.00 (Depends on crop#)	Not determined
Cadmium	0.01	0.05	2
Chromium VI	0.10	1.00	Not determined
Cobalt	0.05	0.10	Not determined
Copper	0.20	5.00	140
Fluoride	1.00	2.00	Not determined
Iron	0.20	10.00	Not determined
Lead	2.00	5.00	260
Lithium	2.50 (0.075 for citrus crops) – same trigger due to toxicity to plant		Not determined
Manganese	0.20	10.00	Not determined
Mercury	0.002	0.002	2
Molybdenum	0.01	0.05	Not determined
Nickel	0.20	2.00	85
Selenium	0.02	0.05	10
Uranium	0.01	0.10	Not determined
Vanadium	0.10	0.50	Not determined
Zinc	2.00	5.00	300

NOTES:

*** If this limit is reached, a site specific risk assessment should be undertaken**
 # Short term trigger levels for Boron:

Concentration (mg/L)	Crop Type for which upper limit
< 0.5	Lemon
0.5 – 1.0	Tree fruits (peach, cherry, plum), grape, strawberry, onion, garlic, beans, sweet potato, Jerusalem artichoke, wheat, barley, sunflower, sesame, lupin
1.0 – 2.0	Capsicum, carrot, cucumber, pea, potato, radish
2.0 – 4.0	Artichoke, cabbage, celery, corn, lettuce, squash, turnip, tobacco, oat, clover, mustard
4.0 – 6.0	Beetroot, parsley, tomato, sorghum, vetch, sugar beet
6.0 – 15.0	Asparagus

Use of an alternative source of water - treated wastewater (reclaimed water)

Licence requirements and planning

The use of reclaimed water in agricultural production carries risk for the environment, human and stock health, and food product safety, thus can be a potential legal liability for water users, the authority supplying the water, and ultimately government. For this reason there are many special planning and licensing requirements governing agricultural use of reclaimed water, managed by EPA Victoria. A summary of EPA Victoria's planning and monitoring requirements for agricultural use of reclaimed water is shown in **Table 8**.

Issues associated with reclaimed water include:

- Water quality – elevated salinity, nutrient levels; presence of contaminant hydrocarbons, detergents and heavy metals (depending on inflows to the water treatment facility and the treatment processes used).
- Potential for contamination of groundwater and surface water systems if not properly managed.
- Public health – microbiological contamination through presence of pathogens, presence of endocrine disrupting compounds (to which embryos/foetuses are particularly vulnerable), and heavy metals available to plants in the water may pose human/animal health risks at concentrations that are not toxic for plants.
- Public and market perceptions of products grown using reclaimed water.

To address these issues, irrigators planning to use reclaimed water are required by the EPA to develop an Environment Improvement Plan.

The level of detail in an Environment Improvement Plan (EIP) should reflect the scale of operation, potential human or livestock exposure and the likely level of environmental risk. Environmental Improvement Plans are expected to address:

- Planned use, reclaimed water quantity and quality (Class)
- Site selection/land capability assessment details
- Reclaimed water transport/distribution systems
- Site controls (access, OH&S)
- Inspection and maintenance programs
- Contingency plans
- Monitoring, reporting, QA and auditing
- Irrigation system controls (methods, operation and maintenance procedures)
- Winter storage facilities and overflow controls
- Drainage and stormwater runoff collection & recycling facilities and controls
- Groundwater protection (offsite impacts of leaching, nutrient loss, monitoring)
- Spray drift and buffer distances
- Salinity manage programs (maintenance of soil structure, leaching methods, off site impacts)
- Irrigation scheduling method
- Crop planning/manage for sustainable nutrient utilisation (fertiliser planning considering nutrient levels in reclaimed water)
- Management of algal blooms

Your proposed reclaimed water supplier should assist with development of the EIP. It is also advisable to discuss your plans with a regional EPA Victoria Officer, to see whether the plan will need to be signed off by the EPA, an EPA endorsed auditor or another authority.

Many agricultural industries have adopted food quality assurance programs to manage product safety. While this document outlines EPA guidelines for use of reclaimed water in agriculture, it is advisable to seek specific advice on product safety regulations, codes, issues, risk and quality systems relating to the use of reclaimed water in your industry. Suggested contacts include Andrew Hamilton at the Institute for Horticultural Development (DPI Knoxfield – ph. 03 9210 9222), the Vegetable Growers Association of Victoria (ph. 03 9210 9376), Dairy Food Safety Victoria (ph. 03 9426 5999), and the Victorian Meat Authority (ph. 03 9685 7333).

Table 8: Summary of planning and monitoring requirements for agricultural use of reclaimed water (from EPA Victoria 2003)

Water Class	Agricultural purpose	Requirements that are irrigators' responsibilities	Water quality monitoring – water supplier responsibility*
A	Crops grown < 1m above ground, in direct contact with water or consumed raw or sold uncooked or unprocessed.	· Environment Improvement Plan · Application rates managed to protect soils, groundwater and surface water quality. · Appropriate signage · Monitoring and audit programs	· Continuous: turbidity, disinfection efficacy · Daily: disinfection systems · Weekly: pH, BOD, SS, *E.Coli* · Other: nitrogen, phosphorus levels –need to set frequency as appropriate
C	Crops not in direct contact with water or grown > 1 m above ground or sold cooked or processed. Pasture and fodder for grazing animals other than pigs.	· Environment Improvement Plan · Application rates managed to protect soils, groundwater and surface water quality. · Restricted public and stock access during irrigation and for 4 hours after irrigation or until dry. · Specific controls (eg withholding periods, rules for dropped produce or processing before sale, helminth treatment for water used for cattle/dairy grazing) · Appropriate signage · Monitoring and audit programs	· Weekly: *E.Coli* · Monthly: pH, BOD, SS · Other: nitrogen, phosphorus levels –need to set frequency as appropriate
B	Pasture and fodder for dairy animals, livestock drinking water (not pigs), washdown water for dairy sheds and stockyards (not milking equipment).	· Environment Improvement Plan · Application rates managed to protect soils, groundwater and surface water quality. · Restricted public and stock access during irrigation and for 4 hours after irrigation or until dry. · Specific controls (eg withholding periods, helminth treatment for water used for cattle/dairy grazing) · Appropriate signage · Monitoring and audit programs	· Daily: disinfection systems · Weekly: pH, BOD, SS, *E.Coli* · Other: nitrogen, phosphorus levels –need to set frequency as appropriate
D	Non food crops (turf, flowers, forestry, woodlots) or aquaculture (not for human consumption – ornamental fish).	· Environment Improvement Plan · Application rates managed to protect soils, groundwater and surface water quality. · Restricted public access or harvesting during irrigation and for 4 hours after irrigation or until dry. · Appropriate signage · Monitoring and audit programs	· Weekly: *E.Coli* · Monthly: pH, BOD, SS · Other: nitrogen, phosphorus levels –need to set frequency as appropriate

* For quality assurance purposes (and for management of nutrient regimes) it is advisable for irrigators to maintain records of the supplied water quality. This should be obtained from the supplier.

Accessibility and yield

Access to a reliable volume of reclaimed water in many cases will be constrained by distance to the nearest large urban centre (or its wastewater treatment facilities). Many urban water authorities now operate schemes for agricultural reuse of reclaimed water, so it is advisable to contact your local urban water authority to determine the potential for access to reclaimed water. Volumes of available reclaimed water may fluctuate throughout the year, such that a storage facility may be required on your property. This may also be subject to special licensing requirements.

Water quality suitable for use

In addition to the water quality recommendations outlined in the section "Groundwater – water quality suitable for use" **(page 13)**, the use of reclaimed water in agriculture is subject to a number of recommended minimum standards for water quality parameters.

In 2003 the Victorian EPA classified reclaimed water into four groups according to levels of treatment, and then specified the agricultural purposes for which water of that quality may be used **(Table 9)**. The EPA has also made specific recommendations regarding appropriate irrigation methods and required management controls for the use of reclaimed water for different agricultural purposes **(Table 10)**. These restrictions are designed to minimise risk to consumers of the agricultural products. Separate conditions exist to prevent degradation of the environment. These are outlined in the section "Fitting in with farm infrastructure and sustainability issues" **(page 23)**.

Table 9: Classes of reclaimed water and associated acceptable agricultural uses (from EPA 2003)

Water class	Indicative water quality objectives - medians for 12 month period	Treatment processes to get to desired quality*	Recommended Agricultural Use
A	< 10 *E.coli* org/100 mL Turbidity < 2NTU <10/5mg/L BOD/SS pH 6 – 9 1 mg/L Cl_2 residual	Tertiary and pathogen reduction with sufficient log reductions to achieve: <10 *E.coli* per 100 mL <1 helminth per litre < 1 protozoa per 50 litres < 1 virus per 50 litres	· Raw human food exposed to reclaimed water · Dairy cattle grazing/fodder, livestock drinking (not pigs) · Cooked/processed human food crops, or selected crops not directly exposed to reclaimed water · Grazing/fodder for cattle, sheep, horses, goats etc · Non-food crops, woodlots, turf and flowers
B	< 100 *E.coli* org/100 mL pH 6 – 9 < 20/30mg/L BOD/SS	Secondary and pathogen (including helminth reduction) reduction	· Dairy cattle grazing/fodder, livestock drinking (not pigs) · Cooked/processed human food crops, or selected crops not directly exposed to reclaimed water · Grazing/fodder for cattle, sheep, horses, goats etc · Non-food crops, woodlots, turf and flowers
C	< 1000 *E.coli* org/100 mL pH 6 – 9 < 20/30mg/L BOD/SS	Secondary and pathogen reduction (including helminth reduction for cattle grazing use schemes)	· Cooked/processed human food crops, or selected crops not directly exposed to reclaimed water · Grazing/fodder for cattle, sheep, horses, goats etc. Diary cattle grazing allowed, subject to 5 day withholding period after irrigation. · Non-food crops, woodlots, turf and flowers
D	< 10000 *E.coli* org/100 mL pH 6 – 9 < 20/30mg/L BOD/SS	Secondary	· Non-food crops, woodlots, turf and flowers

NOTE: * nutrient reductions to nominally 5 mg/L total nitrogen, and 0.5 mg/L total phosphorus are required where re-use scheme poses significant risk of offsite movement of reclaimed water

Table 10: Reclaimed water - detailed recommendations regarding water class, irrigation method and management controls for specific agricultural purposes (from EPA, 2003).

Agricultural reuse category	Specific examples	Minimum water class	Permitted Irrigation methods	Key management controls
Raw human food crops exposed directly to reclaimed water	Crops grown close to ground and consumed raw (eg cabbage). Root crops consumed raw (eg carrots)	A	Unrestricted	None
Raw human food crops not exposed directly to reclaimed water	Crops grown > 1 m above ground and eaten raw (eg apples, apricots, table grapes, olives)	A	Unrestricted	None
		C	Flood, furrow, drip or subsurface	Dropped produce is not to be harvested
Human food crops skinned, peeled or shelled before consumption	Lemons, limes, nuts, melons	A	Unrestricted	None
		C	Flood, furrow, drip or subsurface	Produce should not be wet from reclaimed water at harvest. Dropped produce is not to be harvested
Human food crops cooked (> 70 deg C for 2 minutes) or processed before sale to consumers	Wheat, wine grapes	C	Unrestricted	Produce should not be wet from reclaimed water at harvest.
Crops not for consumption	Woodlot, turf, flowers	D	Unrestricted	Restricted public access to application area. Harvested product not to be wet from reclaimed water when sold.
Irrigated pasture and fodder production*	Dairy animals	B (with helminth reduction)	Unrestricted	4 hour withholding period following irrigation before use pasture or fodder.
		C (with helminth reduction)	Unrestricted	5 day withholding period following irrigation before use pasture or fodder
	Beef cattle	C (with helminth reduction)	Unrestricted	4 hour withholding period following irrigation before use pasture or fodder.
	Sheep, goats, horses etc	C	Unrestricted	4 hour withholding period following irrigation before use pasture or fodder.
Livestock drinking water*		B	N/a	Reclaimed water with blue green algal bloom unsuitable for stock watering
Washdown water*	Eg dairy sheds	B	N/a	Not to be used for milking machinery

NOTE: * Controls to ensure pigs do not come into contact with reclaimed water or are not exposed to reclaimed water irrigated pasture or fodder should be in place.

Fitting in with farm infrastructure and sustainability issues

The quality of the reclaimed water may affect your existing farm infrastructure by accelerating corrosion or fouling. For spray and drip irrigation systems, filters will be required to reduce incidence of blockages.

Use of reclaimed water carries a responsibility to ensure that loss of the water (or nutrients, salts and metals contained in the water) to surrounding groundwater and surface water systems, and the wider environment, are minimised. Special provisions in terms of storage facilities, runoff and drainage management will be required in order to obtain approval for use of reclaimed water.

Storages

Storages that are intended to hold reclaimed water require an appropriate ponding base and embankment lining to minimise seepage and protect groundwater systems. The appropriate design would be based on an assessment of the size and depth of the storage, the likely reclaimed water quality, underlying geology and groundwater vulnerability. A clay liner may be suitable in most circumstances, with suggested liner thicknesses shown in **Table 11**. You may be required to monitor groundwater quality in the vicinity of the storage to ensure no groundwater contamination is occurring. This could involve the installation of observation bores and a long term monitoring program.

Runoff and drainage requirements

Aspects of particular concern include nitrate leaching to the groundwater system, phosphorous leaching to the groundwater or accumulating in surface soils where there is an erosion risk, the accumulation of salt in surface soils, or potential for excessive leaching of salt to the groundwater system.

To minimise nitrate and phosphorus loss, the nutrient loadings in the water should be matched to plant requirements. **Table 12** provides a rough indication of likely nutrient loadings and approximate plant uptake of nutrients. Salinity control measures may also be required depending on the reclaimed water quality **(Table 13)**.

Table 11: Recommended lining for storages containing reclaimed water (from EPA 2003)

Storage capacity	Depth	Liner requirement
< 3ML and intermittently filled	<1.5 m	Surface compacted clay, permeability < 10^{-9} m/s
3 ML or >3 ML (permanently filled)	< 1.5 m	300 mm thick clay liner, permeability < 10^{-9} m/s
	3 m	600 mm thick clay liner, permeability < 10^{-9} m/s
	> 5 m	1 m thick clay liner, permeability < 10^{-9} m/s

Table 12: Typical nutrient loadings and plant uptake rates (from EPA Victoria 2003)

Nutrient	Reclaimed water treatment level		Plant annual uptake rates (kg/ha/yr)	
	Secondary	Tertiary	Typical	Rarely exceed
Nitrogen	10 – 30 mg/L	Up to 5 mg/L	200	500
Phosphorus	6 – 10 mg/L	Up to 1 mg/L	20	50

Table 13: Requirement for salinity controls given salinity levels in reclaimed water (from EPA Victoria 2003)

Salinity of reclaimed water (Total dissolved salts, mg/L)	Requirement for salinity control
Up to 500	Use without significant risk, provided appropriate leaching occurs
500 - 3500	Risk to groundwater, soil and the crop – require salinity controls
> 3500	Should not be used for irrigation

It is recommended that any area irrigated using reclaimed water should have tailwater collection and recycling facilities in place to capture and reuse any irrigation runoff, or the first flush of stormwater if rain occurs during or immediately after an irrigation event. The collection facility should be operated so that it is almost empty following irrigation, allowing the capture of any contaminated rainfall. If there is high potential for reclaimed water runoff to be lost to the surrounding environment, then the use of Class A or B reclaimed water should be considered.

In addition to a tailwater runoff collection system, certain buffer zones are recommended to minimise the risk of water loss to the surrounding environment. These cover potential loss to surface waters and the potential for spray drift **(Table 14)**. If high pressure sprays are used, it is recommended to increase the buffer distances for spray drift.

Reliance on water trading

This approach to securing water supply probably carries the greatest amount of risk. The 1989 Water Act provides for trading of irrigator entitlements or licences on a temporary or permanent basis, in both regulated and unregulated systems. The specific rules regarding water trade are set out in the Ministerial Guidelines for Managing Diversion Licences (October 2002). A Streamflow Management Plan may specify variations to those rules for the particular catchment to ensure the aims of the SFMP are achieved.

Increasing your water entitlement by purchasing entitlement from another user in permanent or temporary trade may improve your reliability of supply in dry years by ensuring access to a greater amount of water whilst rosters are in place, however it does not guarantee access to that full volume of water in all years and you will still have to comply with rosters, restrictions and complete bans on extraction set out by the SFMP conditions. Prices for water may be at a premium during dry periods and there is the possibility no water will be available for trade at those times anyway.

For more information about water trading in your area, refer to the relevant Streamflow Management Plan and contact your rural water authority.

Table 14: Recommended buffer distances to reduce impact of water loss on surrounds (from EPA Victoria 2003)

	Recommended buffer distance between application site and surface water body or property boundary
Surface water body recommendations (based on irrigation methods)	
Flood or high pressure spray irrigation	100 m
Low pressure spray irrigation	50 m
Trickle or subsurface irrigation	30 m
Spray drift recommendations (based on class of water used)	
Class A water	No recommended buffer
Class B water	At least 50 m
Class C water	At least 100 m
Class D water	At least 100 m

WATER MANAGEMENT OPTIONS TO HELP REDUCE OVERALL WATER USE

There are two basic approaches to reducing the overall amount of irrigation water used by your enterprise: you can apply the same volume of water per hectare over a smaller area, or you can water the same number of hectares but apply a smaller volume of water per hectare. It may be possible to reduce the amount of water applied per hectare either by improving some aspect of irrigation fundamentals (timing, volume or application method), or by re-assessing the need to use irrigation water for some other purpose (eg frost control).

The two approaches are summarised in **Figure 4**. In practice, a combination of the two approaches may be the best solution for your enterprise.

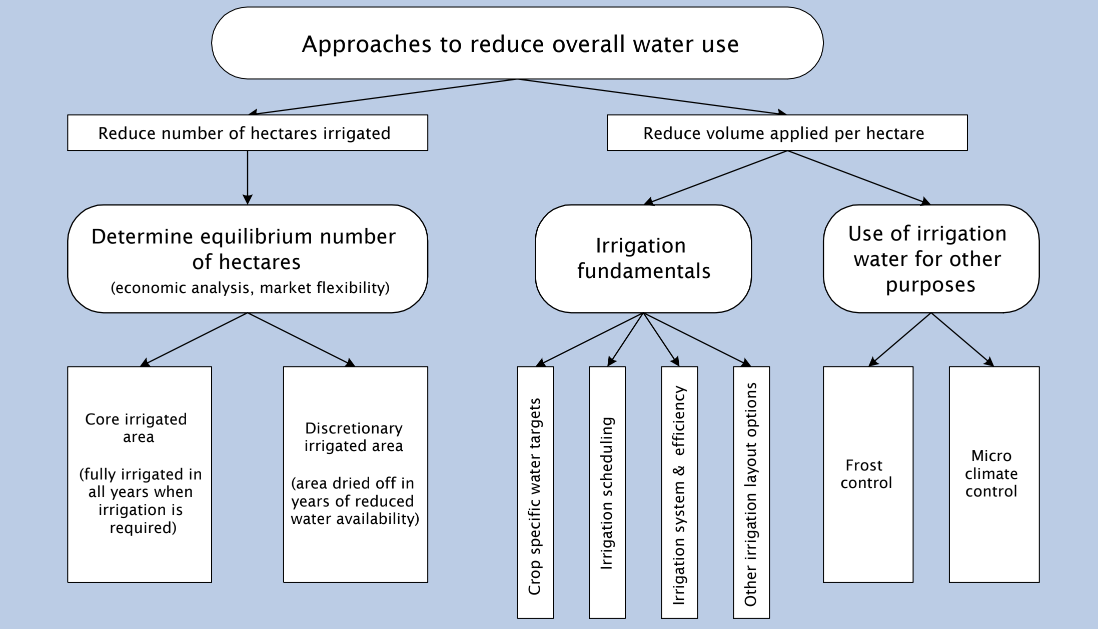

Figure 4: Summary of approaches to reduce overall water use

Reducing the number of hectares irrigated

This approach requires a full economic analysis of the requirements for your business. This should determine the minimum amount of crop to produce annually in order to remain viable, and an analysis of the market in terms of its flexibility to a changing supply of product. The analysis should allow you to determine an equilibrium number of hectares to irrigate, based on say a ten year period, classed in two categories.

The first category is the 'core irrigated area', which should be of sufficient extent to produce the minimum amount of crop for your business to remain viable. This area will be fully irrigated in all years when irrigation is necessary, so that any measures taken to secure your water supply should ensure an adequate volume of water is available to irrigate this area.

The second category is the 'discretionary irrigated area'. This area may be planted and irrigated in years when water use is unlikely to be restricted, allowing increased production and potential for increased profit. In years when water availability is reduced, this area is allowed to dry off to ensure adequate water availability for the core irrigation area. Given this fluctuating irrigation water availability, it is likely that this area may be planted to a different crop type, for example an annual rather than perennial crop.

Figure 5 illustrates this approach for a hypothetical raspberry farm, whose main focus is the production of high quality fresh raspberries. The total area of the farm is 25 hectares, of which 11 hectares is set aside for raspberry production (including fallow or replant areas). This is the core irrigated area for the farm. An additional 8 hectares has been set aside for vegetable production in years where water availability is not constrained. The irrigation storage has a 70 ML capacity, which will fully irrigate 11 hectares of raspberries with an allowance for evaporation loss.

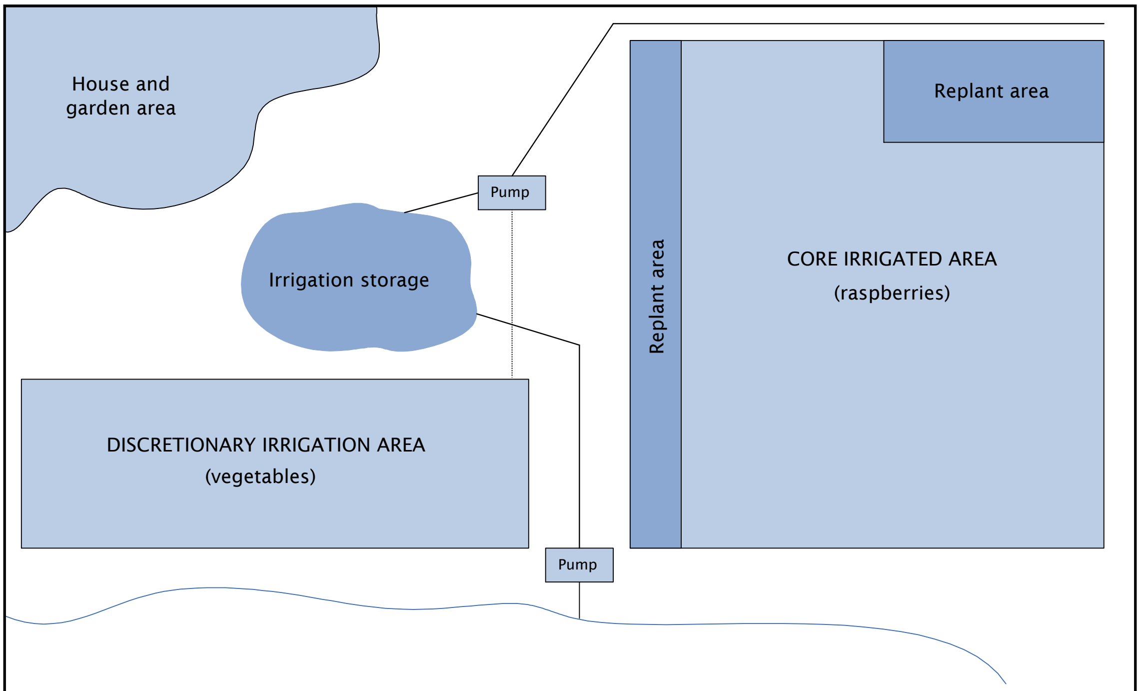

Figure 5: Reducing the number of hectares irrigated, on a hypothetical rasberry farm. The layout sets out core and discretionary irrigated areas.

Reducing the volume of water applied per hectare - irrigation fundamentals: timing, volume and application method

The fundamental reason for irrigation is to maintain plant production at an optimum level. Irrigation is concerned with concepts of evapotranspiration (plant water use), the availability of soil moisture, and how the level and impacts of water stress vary depending on the timing of the stress in relation to the crop's life stage. This forms the basis of irrigation scheduling – deciding when to apply irrigation water, and how much to apply. The timing and volume applied in irrigation events will be constrained by the capacity of your current irrigation and water distribution system.

This section provides an overview of irrigation fundamentals, in terms of crop water use, irrigation scheduling strategies and methods, the range of available irrigation systems, steps to monitor irrigation efficiency, and irrigation layout options. For more specific information about a topic, refer to the list of additional reading at the end of the section.

Crop water use

In a water-constrained environment, it is worth considering how much water various crops will use in order to determine what may be better suited to your conditions or the likely irrigation water availability.

Table 15 shows the maximum annual water requirement for certain crops at various sites throughout Victoria. The targets were calculated using data from the Climatic Atlas of Australia-Evapotranspiration (2001) and crop factors for evapotranspiration outlined in Allen *et al* (1998). They represent the upper limit on crop water requirements, assuming full irrigation. If local recommendations by the Department of Primary Industries are available for your crop type, you should follow those recommendations.

Whilst **Table 15** shows maximum annual water requirements, plants will require differing amounts of water throughout the year, in response to changing climate conditions and their own growth stage **(see Figure 6)**. Thus although an area may experience sufficient rainfall to satisfy a plant's annual water requirements, sufficient water may not be available for critical plant growth stages.

Table 15: Estimated maximum annual water requirement (ML/ha) for a variety of crops, and average annual rainfall, for selected sites in Victoria. For each location, crops that in an average year could receive sufficient* water from rainfall are shown in a darker shade.

	Bairnsdale	Ballarat	Bendigo	Coldstream	Hamilton	Horsham	Latrobe Valley	Mildura	Myrtleford	Noojee	Omeo	Shepparton	Wangaratta	Warrnambool	Werribee
Legumes, cucumbers & melons	7	7	9	7	7	9	7	10	9	6	7	10	10	6	8
Solanums, roots & tubers	8	9	10	9	9	11	8	13	10	8	8	12	11	8	10
Brassicas, carrots, garlic	9	10	11	9	10	11	9	13	11	9	9	12	12	9	10
Berries	6	6	8	6	6	8	6	9	8	6	6	9	8	6	7
Grapes	5	5	6	5	5	6	5	6	6	4	5	6	6	5	6
Stone fruit	6	7	8	6	7	8	6	10	8	6	6	9	9	6	7
Pome fruit	7	7	9	7	7	9	7	10	9	6	7	10	10	6	8
Citrus fruit	6	7	9	7	7	9	6	10	9	6	6	10	9	6	8
Cereals and oils	6	6	8	6	6	8	6	9	8	6	6	9	8	6	7
Pasture & lucerne	7	8	9	7	8	10	7	10	9	7	7	10	10	7	8
Olives	6	7	9	7	7	9	6	10	9	6	6	10	9	6	8
Walnuts	7	8	10	7	8	10	7	11	10	7	7	10	10	7	9
Hops	7	8	9	7	8	10	7	10	9	7	7	10	10	7	8
Average annual rainfall	7	7	5	10	7	4	8	3	9	11	7	5	6	9	5

* While the total volume of rainfall may be sufficient to meet a crop's needs, the distribution of the rainfall over the year may not match plant requirements.

For specific information about the changing water requirements of the various crops, refer to Boland *et al* 2002, Qassim *et al* 2002, and the publications by Goodwin.

Irrigation scheduling

Irrigation scheduling is the process of deciding when to apply irrigation water, and how much water to apply. The mechanics of irrigation scheduling consists of a strategy (approach to irrigation), and a method for implementing the strategy.

An alteration to your current irrigation scheduling practices may slightly reduce overall water use, depending on current practice. In some cases improvements in irrigation scheduling may be constrained by your current irrigation system. For example, it can be difficult to apply a precise volume of water using surface irrigation methods. It is worth reading some of the more specific information about irrigation scheduling practices for different horticultural crops, to see the latest advances for your industry.

Irrigation strategies

Irrigation strategies can include full irrigation, regulated deficit irrigation (RDI) and partial rootzone drying (PRD).

The aim of "full" irrigation is to replace water used since the previous irrigation or rainfall event before the onset of water stress. Thus the timing and amount of irrigation required depends on the rate of plant water use (evapotranspiration), evaporation from the soil surface and the amount of available water stored in the rootzone. "Full" scheduling supplies sufficient water to minimise plant water stress, and with allowances for irrigation system inefficiency should maximise crop yield. However, depending on the crop, irrigation water may go into non-productive parts of the plant, weeds or into cover crop growth, reducing overall water efficiency. Full irrigation will generally allow a certain amount of leaching of salts and nutrients that have accumulated in the soil.

Regulated deficit irrigation (RDI) is based on strategic impositions of water stress to control vegetative growth, increase fruit quality and reduce overall water use. RDI has been shown to maintain fruit yield in peach and pear orchards, and increase wine quality attributes in viticulture, and is currently under investigation for other horticultural industries. The use of RDI requires confidence in knowledge of soil moisture conditions, and does not work for all horticultural industries. Depending on irrigation water quality, use of RDI may lead to increased soil salinisation if inadequate leaching occurs.

The concept of 'partial rootzone drying' (PRD) is fairly new. Under PRD, a portion of the rootzone is allowed to dry out, suppressing shoot growth and leaf water loss (transpiration), whilst the other portion is fully irrigated, for a set period and then the treatments are switched. The theory is that PRD reduces vegetative vigour and unwanted canopy shading, and thus reduces overall water use. PRD appears to work in some vineyards, and is currently under investigation in pears and peaches. Application of PRD requires a high degree of precision, automation, soil sensors, and an appropriate site setup to be applied correctly. The technique is essentially still at a research stage. PRD has similar issues to RDI in terms of needing an adequate leaching regime if water quality is a concern, with greater initial capital costs and high maintenance requirements.

Irrigation scheduling methods

Irrigation scheduling methods range from simple (observation, time based) through moderately complex (evaporation based) to detailed assessments of conditions (evapotranspiration or soil moisture monitoring). These methods are summarised in **Table 16**.

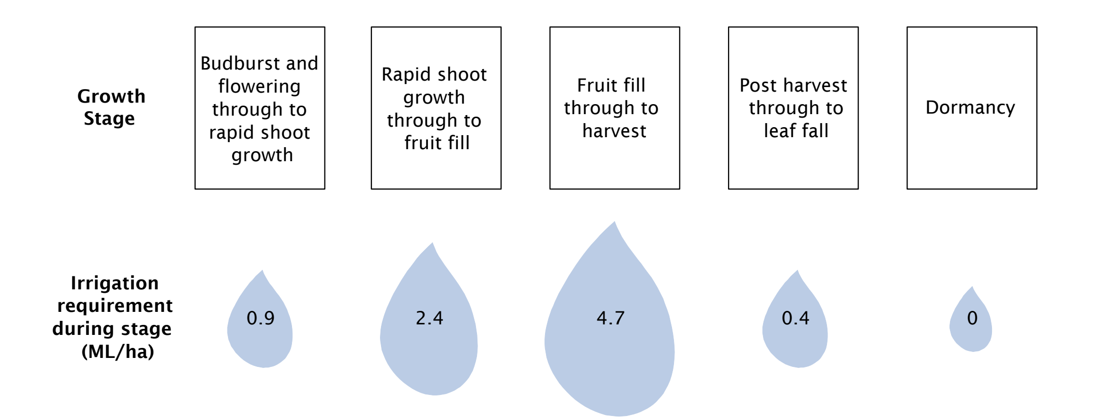

Figure 6: Changing water use for an apple tree in the Goulburn Valley over a season

Table 16: A summary of irrigation scheduling methods

Method	Description	Benefits	Issues
Shovel/auger	Physical inspection of soil to assess dryness	Quick, with minimal equipment requirements	Not accurate, destructive method, and not predictive.
Time based	Irrigations scheduled on fixed time interval, which may vary according to season/month. Usually based on long-term average climate conditions.	Easy to plan around, minimal equipment required. Works well in a stable/ consistent climate.	Can waste water if no strategy to allow for rain. No allowance for day to day variation in climate.
Evaporation	Irrigations are scheduled when it is estimated that the plant has used all available soil moisture from irrigation and rainfall, based on local or on-site daily evaporation. The irrigation trigger is a set cumulative evaporation minus rainfall deficit. Evaporation measured daily using Class A pan evaporimeter.	Relatively simple but puts greater scientific rigour into scheduling. Adapts to changing climatic conditions.	Need strategy to adjust for rainfall. Can have siting issues. Open water evaporation is greater than plant evapotranspiration so requires local knowledge/ adjustment. Daily time commitment.
Evapo-transpiration	Similar to using evaporation, but uses more climate data (temperature, radiation, wind and relative humidity) in the calculation of evapotranspiration of a reference crop (grass). Involves use of automatic weatherstation.	More rigour than using evaporation because is a better reflection of plant water use.	Greater volume input data needed. Need good operating skills/ knowledge. Time. Expensive. Requires energy resources to operate
Soil Moisture Monitoring	Monitoring of soil moisture conditions (continuous or daily) in plant rootzone to schedule irrigations when set trigger moisture condition is reached. Many types of sensors available, with varying associated levels of complexity, labour and cost.	Best indication of how much water is available to plant, particularly after rainfall.	Need to understand output & how relates to irrigation. Will need to find a representative site given is often a point based measurement – issues with spatial variation throughout your irrigated area. More complex than other methods, more costly, and may have greater labour requirements. May require energy resources to operate.

Irrigation methods and measuring their efficiency

Assessing irrigation efficiency

Prior to investing in another irrigation application method, it is worth considering or evaluating the effectiveness of your existing method, to see if it could be improved.

One approach is to calculate your agronomic water use efficiency. This is commonly defined as the quantity of product produced per irrigation water input, with units tonnes or kilograms per megalitre:

$$\text{Water use efficiency (t/ML)} = \frac{\text{yield (t/ha)}}{\text{irrigation water applied (ML/ha)}}$$

Calculated annually, it can be a useful indicator of how efficient your irrigated enterprise is from year to year, by linking crop yields to applied water. However, calculating water use efficiency will not assess the effectiveness of your chosen irrigation method nor shed light on aspects that might be improved. For greater insights into irrigation effectiveness, it is worth assessing the application efficiency and distribution uniformity.

Application efficiency is a measure of an irrigation method's ability to apply a target 'depth' of irrigation to the field. It is calculated for a given irrigation event according to the formula:

$$\text{Application efficiency (\%)} = \frac{\text{Average depth applied to rootzone}}{\text{Average depth applied to field}} \times 100\%$$

In theory every irrigation system should be able to achieve 100% application efficiency. However, due to variation in individual management or design, most reported application efficiencies peak at around 90% efficiency. Surface irrigation methods are reported to have application efficiencies in the 40 to 90% range, compared to 60 to 90% for sprinklers, and 80 to 90% for micro-irrigation methods (Clemmens 2000). **Figure 7** shows a comparison of the reported application efficiencies for a range of irrigation methods.

The uniformity of water application can be as important as the overall water application efficiency. Uneven watering means that some areas will be over-watered whilst other areas are under-watered and potentially water stressed. Prolonging irrigation duration to allow under-watered areas to receive the target irrigation depth can lead to water wastage in the remaining areas through increased surface runoff or deep drainage. Poor irrigation uniformity can lead to yield reductions from waterlogging or water stress.

For surface irrigation methods, the interaction between flow rates, soil hydraulic properties such as the final infiltration rate and irrigation duration will control the uniformity of application. If flow rates exceed the final infiltration rate of the soil there is increased chance of runoff and under-application. However, if flow rates are too low there is increased opportunity for infiltration during an irrigation event, potentially leading to increased deep drainage loss. Another critical factor for surface irrigation methods is the quality of the grading of soil surfaces – it is very difficult to achieve a high level of uniformity without well-graded field surfaces.

In pressurised irrigation setups, variation in operating pressure will affect flow rates and sprinkler/emitter water distribution patterns, decreasing irrigation uniformity. Variation in pressure and flows can arise from:

- wear or blockage of sprinklers/emitters,
- an incorrectly designed system, or conversely a correctly designed system that is not being used in the intended manner,
- leakages within the system, or
- non-optimal pump performance.

If a system operates below the designed pressure, large water droplets will be thrown further than small water droplets leading to a ‘doughnut’ pattern of water distribution. If operated above the design pressure, water will fall close to the sprinkler/emitter or fine droplets will form, leading to misting and increased wind drift/evaporative losses.

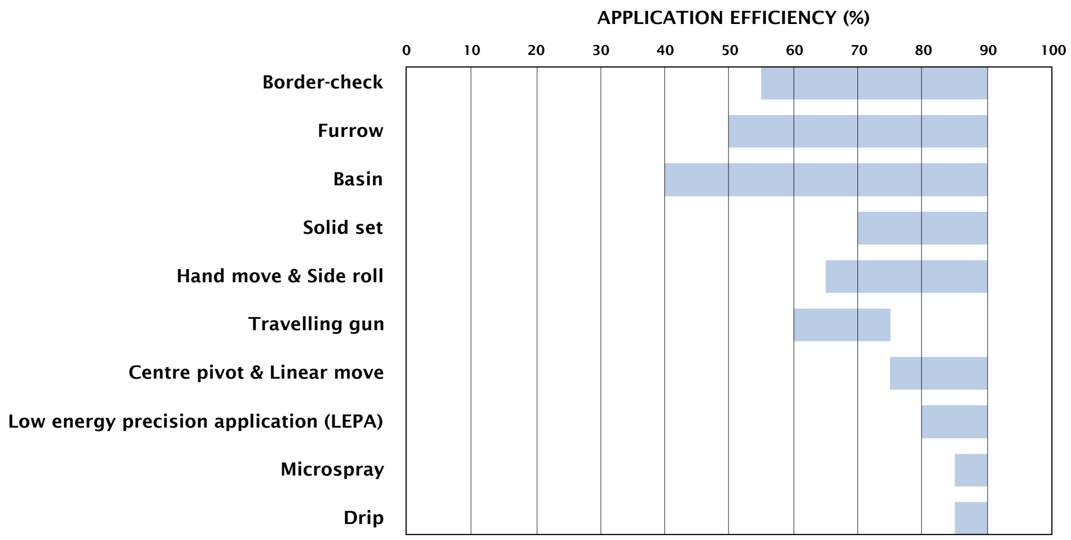

Figure 7: Reported application efficiencies for different irrigation methods (from Clemmens 2000)

The most widely recognised method for measuring the uniformity of irrigation is to calculate the distribution uniformity for a given irrigation event. Distribution uniformity is defined by:

$$\textit{Distibution Uniformity (\%)} = \frac{\textit{Average depth applied in lower quarter}}{\textit{Average depth applied over field}} \; X\ 100\%$$

where the average depth applied in the lower quarter is the average depth for the quarter of the field that received the least amount of water. Sprinkler and micro-irrigation methods should have a distribution uniformity greater than 85%.

Approaches for measuring the performance of surface and pressurised irrigation methods are shown in **Table 17 and Table 18** respectively. Any assessment of irrigation method performance should be made under 'typical' conditions with respect to setup and irrigation management.

Table 17: Steps to measure the performance of surface irrigation

Step	Measure	How
1	Measure depth of water applied to the field	The total depth of irrigation water applied to the bay/furrow/basin (in m) is equal to the volume of water applied (m^3) minus any tailwater runoff, divided by the area of the bay/furrow/basin (m^2).
2	Measure depth of water applied to rootzone at several sites within the field	To do this, you will need to get a measure of the soil water content in the rootzone prior to irrigation, the rootzone soil moisture content after irrigation and the amount of evapotranspiration that occurred between the two readings. This allows you to calculate the depth applied to the rootzone: Depth applied to rootzone (m) = (soil moisture content after irrigation (cm^3/cm^3) X depth of soil of the observation (mm)) + evapotranspiration between observations (mm) – (initial soil moisture content (cm^3/cm^3) X depth of soil of the observation (mm)) X1000. It is recommended to take measurements of the depth applied to the rootzone in at least four locations in the bay/furrow/basin. The accuracy of the uniformity calculation will improve as the number of individual measurements increases. The overall calculation of application efficiency will use the average of all these depth measurements, whilst the distribution uniformity calculation will use the average of some of the depth measurements.
3	Calculate application efficiency	The application efficiency is calculated by dividing the average depth applied to the rootzone (m) by the total depth of irrigation water applied (m), then multiplying by 100 to get the percentage efficiency.
4	Calculate distribution uniformity	Firstly you will need to rank the individual 'depth applied to rootzone' figures, then select the lower quarter of these and calculate the average of the lower quarter observations. For example, if you had calculated the depth applied to the rootzone at 8 sites within the bay/furrow/basin, you would sort the data from highest to lowest applied depth, select the two lowest observations and calculate the average of the two. To calculate the distribution uniformity, divide the average depth applied to rootzone (lower quarter) by the depth of water applied to the field, and multiply this by 100 to get the percentage uniformity.

Table 18: Steps to measure the performance of pressurised irrigation

Step	Measure	How
1	Physical check of components	Check for leaks, suction problems, blockages and if the correct number of sprinklers/ emitters is operating.
2	Pressure and flow check	Measure the pressure/ flow at 'near', 'far', high' and 'low' points within each block and across the system. Compare with the original design standards or the pressure/flow charts for the sprinkler/emitters.
3	Measure mean application rate	For sprinklers: Use catch cans to collect the amount of water applied by the system in a given period. Convert the amount collected in each can from a volume to depth (mm) by dividing by the area of the can, then convert this to mm/hour by dividing by the time period expressed in hours*. The mean application rate is then calculated by dividing the total applied depth per hour (sum of all the depths) by the number of catch cans. For drip systems: Let the dripper run for a few minutes so you can see the wetted area. Then collect the output from the dripper over a measured time interval, and divide this volume by the wetted area to get the depth, and then divide by the time period in hours to get mm/hour. The mean application rate is calculated by dividing the total applied depth per hour (sum of all the depths) by the number of drippers. NOTE: this has assumed that the wetted volume of soil will not vary, and that it is equivalent to a cylinder with a diameter that is the width of the wetting pattern. * If the time period was 5 minutes, this is equivalent to 5/60 hours, or 0.083 hours, so that to get to mm/hour you would divide the depth by 0.083. If 15 minutes, you would divide by 15/60 = 0.25 hours, and so on.
4	Calculate distribution uniformity	To calculate the distribution uniformity, you firstly need to rank the individual depth observations used to calculate the mean application rate, and then select the bottom 'quarter'. For example, if you used 40 catch cans to measure the mean application rate, you would rank the 40 observations in mm/hr from highest to lowest, then select the last 10 observed depths. The next step is to calculate the mean depth of these 'low quarter' observations, by summing the individual observations and then dividing by the number of observations. Finally, to calculate the distribution uniformity, divide the mean depth of the 'lower quarter' observations by the mean application rate, and multiply this by 100 to get the percentage uniformity.
5	Calculate application efficiency	To do this, you will need to get a measure of the soil water content in the rootzone prior to irrigation, the rootzone soil moisture content after irrigation and the amount of evapotranspiration that occurred between the two readings, adjusted for the fraction of soil wetted. This allows you to calculate the depth applied to the rootzone: Depth applied to rootzone (mm) = (soil moisture content after irrigation X depth of soil of the observation (mm) + (proportion of soil surface that is wetted X evapotranspiration between observations) (mm) – (initial soil moisture content X depth of soil of the observation (mm)). The next step is to calculate the total depth of irrigation water applied, which is done by multiplying the mean application rate (mm/hr) by the number of hours for the irrigation. The application efficiency is calculated by dividing the depth applied to the rootzone by the total depth of irrigation water applied, then multiplying by 100 to get the percentage efficiency.

Irrigation methods

With availability of irrigation water becoming more constrained globally, many irrigators are changing their irrigation method to either use less water overall or maximise the area of crop that can be watered using a set volume of water. In Australia, there has been a gradual shift away from surface irrigation methods towards the use of sprinklers and other pressurised systems in horticultural and cropping industries, and more recently in the dairy industry.

While surface irrigation can be efficient, there is generally better control over irrigation when a pressurised system is used, with less water lost through evaporation, runoff or seepage. This also reduces the chance of pesticide or nutrient loss to the surrounding environment. Other benefits include the ability to apply small amounts of water at frequent intervals, thus matching irrigation applications to crop water requirements, which in turn can improve crop yield and quality. Pressurised methods also tend to have lower labour requirements than surface approaches.

In some horticultural and viticultural industries, there has been a shift away from overhead sprinklers to the use of micro-irrigation technology, such as drip, subsurface drip, microspray or microsprinklers. Micro-irrigation generally operates at lower pressures than sprinklers, so has lower energy requirements. With these methods, water is applied to the soil surface or below the foliage, reducing evapotranspirative or interception losses, and also damage to leaves from the water impact or scalding due to poor water quality. All micro-irrigation systems require a filtration system, frequent flushing and water containing few impurities to operate without blockages.

Subsurface drip irrigation has the additional benefit of reducing the opportunity for evaporative water loss. Within the last ten years there has been increasing adoption of subsurface drip irrigation for high value crops such as fruit and vegetables, with increased yields and decreased water use reported. Subsurface drip has also been shown to maintain or increase yield for broadacre cropping of lucerne and maize, generally accompanied by a reduction in overall water use. In a recent DPI experiment in northern Victoria, subsurface drip irrigation increased perennial pasture yield whilst using significantly less water compared to surface (border-check) irrigation, performing comparably to sprinkler irrigation.

Choosing the most appropriate irrigation method for your property is not easy. There are many advantages and disadvantages to each method, and ultimately the decision will depend on the circumstances of your enterprise. Ideally, the irrigation method used by your enterprise should be:

- Appropriate for the predominant soil type,
- Appropriate for the crop type and area of crop
- Designed to apply the correct amount of water to the crop, without excessive losses, and with capacity to meet maximum seasonal demands without the need for round-the-clock operation, and
- Installed, operated and maintained correctly.

A general comparison of different irrigation methods is shown in **Table 19**. If you are seriously contemplating changing irrigation method, it is well worth obtaining more specific information by talking to staff from DPI and similar agencies, irrigation designers, irrigation distributors or other irrigators who have made the change.

Remember, the installation of a more efficient irrigation system does not automatically rule out the occurrence of irrigation runoff or deep drainage – it is possible to flood irrigate using a sprinkler or drip system if incorrectly designed or poorly managed! If you do change your irrigation method, you will also need to change the rest of your irrigation management to ensure you are receiving all the benefits from the new method.

Table 19: Comparison of different types of irrigation methods

Method	Capital Cost*	Pumping Cost	Labour requirements	Application efficiency	Application uniformity	Potential water losses	Comments
Surface irrigation - furrow	Modest to high, depending on land levelling requirements	Low (generally a gravity fed system)	Moderate to high (depending on level of automation)	Low to high, depending on layout/soil properties/ irrigation management	Low to high, depending on layout/soil properties/ irrigation management	Evaporation. Surface runoff. Seepage.	Performance highly variable depending on site setup and strongly influenced by irrigation management. Can have problems with erosion. Irrigation performance may be improved by using surge flow rather than constant flow irrigation. Double row cropping may also reduce overall water use
Surface irrigation - border - check	Modest to high, depending on land levelling requirements	Low (generally a gravity fed system)	Moderate to high (depending on level of automation)	Low to high, depending on layout/soil properties/ irrigation management	Low to high, depending on layout/soil properties/ irrigation management	Evaporation. Surface runoff. Seepage.	Performance highly variable depending on site setup and strongly influenced by irrigation management. Suited to areas of even slope, for crops such as pasture.
Fixed or portable solid set sprinklers	Relatively high	Relatively low to low – operate at medium pressures	Substantial at setup & retrieval; minimal once set up.	High	Good if properly designed with appropriate spacings	Evaporation. Some wind dispersion. Possible surface runoff depending on management.	Suited to high value intensive vegetable, herb & ornamental crops; fixed systems for perennials.
Travelling gun or boom irrigators, with soft or hard hose.	Modest Higher for hard hose systems.	High. High pressure required. Higher for hard hose (increased friction losses). Boom systems use lower pressure.	Modest – lower for hard hose types. Reasonable sized tractor required to move large hard hose machines.	Low to moderate (higher for boom systems).	Low Uneven at start and end of run. Better uniformity with boom. Uniformity depends on overlap of runs.	Wind dispersion. Evaporation. May have excess runoff/ seepage at ends where over-watered.	Very flexible and portable system. Efficiency influenced by degree of overlap between irrigations. Most suited to annual crops with low water requirements.
Long lateral sprinklers (eg Van der Bosch, K-line)	Relatively low	Modest. Significant friction losses in lateral hoses.	High and regular	Low (relies on accuracy in overlap of runs).	Very low - uniformity depends on overlap of runs	Wind dispersion. Evaporation. Minimal surface runoff or seepage.	Low capital cost but high labour requirements. Suited to pasture only. Suits areas with irregular shape or undulating topography.
Centre Pivots	Modest to high	Low to moderate, depending on design pressure.	Low to modest	High to very high	High to very high. May require end gun for uniform application in square paddocks.	Evaporative losses. Some runoff at end of line on large systems (depending on design)	Robust on rolling terrain. If properly designed allows consistent efficient irrigation with minimal labour. Best suited to large areas of crops with high water requirements or of high value.

Table 19: Comparison of different types of irrigation methods (Cont'd)

Method	Capital Cost*	Pumping Cost	Labour requirements	Application efficiency	Application uniformity	Potential water losses	Comments
Linear or lateral move	Modest to high	Low to moderate, higher than centre pivot due to hose friction losses.	Low to modest	High to very high.	High to very high. Most suited to rectangular areas.	Evaporative losses. Some runoff if application rate > infiltration capacity of soil.	If properly designed allows consistent efficient irrigation with minimal labour. Best suited to large areas of crops with high water requirements or of high value. Less appropriate on undulating or irregular terrain.
Micro irrigation – microsprays or minisprinklers	High to very high	Low (operate at low pressure)	Low (seasonal maintenance)	Very high	High	Low evaporative losses. Possible surface runoff depending on management.	Suited to vine and tree crops. Accurate control of irrigation possible, best utilised with sophisticated scheduling methods. Will require filtration system and relatively clean water.
Micro irrigation - drip	High to very high	Low (operate at low pressure)	Low (seasonal maintenance)	Very high	High	Low evaporative losses. Possible surface runoff depending on management.	Wetting pattern will be influenced by soil texture and discharge rate. Suited to vine, tree crops and other forms of horticulture. Accurate control of irrigation possible, best utilised with sophisticated scheduling methods. Will require filtration system and relatively clean water.
Micro irrigation – subsurface drip	High to very high	Low (operate at low pressure)	Low (seasonal maintenance)	Very high	High	Reduced evaporative losses, minimal runoff or seepage.	Suitable for horticulture and pasture irrigation (if properly designed). Flexible (fits into most layouts). Water applied within rootzone minimising losses. Will require filtration system and relatively clean water. May need another irrigation system for crop germination.

* Based on supply and installation of components except power supply.

Dealing with irrigation-induced runoff and drainage

Installation of a tailwater (runoff) collection system, designed to capture irrigation runoff water from the entire irrigated area, is highly recommended for any irrigated land. This water may then be re-used for irrigation, depending on the water quality requirements of your crop or markets.

Drainage is another aspect closely associated with irrigation. It is highly desirable to reduce the incidence of deep drainage under irrigation to prevent contamination of groundwater systems and the rise of water tables. Waterlogging due to high water tables or poor drainage is believed to affect plant growth and reduce crop yield.

For high value permanent plantings such as orchards, it is common practice to either plant on formed hills or install some form of drainage system such as tile drains, to prevent waterlogging within the rootzone. Collection and reuse of this drainage water may be possible, provided it has acceptable water quality. Other approaches to managing irrigation drainage relate to bed layout or design. The use of a raised bed system is essentially concerned with reducing the risk of waterlogging, but may lead to decreased water use for some crops, or facilitate the capture of drainage water. This is currently under experimental investigation for a variety of crops at locations in Victoria and NSW by DPI, NSW DPI and CSIRO.

Recommended practices and further training opportunities

A recent benchmarking study carried out in the Riverland and Sunraysia districts of South Australia/Victoria developed a list of recommended irrigation practices, based on the best performing irrigated enterprises in that study **(Table 20)**. The list is designed to provide guidance about principles for good management rather than setting out prescriptive recommendations.

There are many courses designed to provide information about irrigation (timing, volume and mechanics of applying irrigation water) and how to deal with drainage water, targeting specific industries or regions where irrigation takes place. These include NSW Agriculture's "Water Wise on the Farm", the Irrigation Association of Australia's "Irrigation Learning Guides", and Tasmania's "Wise Watering Irrigation Management Course". In the traditional irrigation areas of Victoria, courses on irrigation management have been conducted periodically over the last 30 years, with most recent efforts taking place as part of the "Megabucks from Megalitres" project. Irrigation management courses have also been conducted in the Mallee, North-East, Shepparton Irrigation and Gippsland regions through the "Water for Growth" initiative. Contact your local Department of Primary Industries office or Industry Association to see if an irrigation management course may be available for you.

Table 20: Recommended irrigation practices (from Skewes and Meissner, 2001)

1	Rate irrigation as a high priority within your farm management
2	Get to know the soils on your property (water-holding capacity, depth of rootzone)
3	Design and maintain irrigation systems correctly
4	Monitor all aspects of an irrigation event (before, during and after)
5	Use objective monitoring tools to schedule irrigation (not intuition/calendar) and take other factors into account (observation of plants, digging holes to observe soil water, runoff/drainage following previous irrigation)
6	Retain control of irrigation scheduling (do not rely completely on technology or consultants)
7	Remain open to new information

Reducing the volume of water applied per hectare - use of water for frost protection

Frosts damage plants by causing plant cells and tissues to freeze, leading to the formation of internal ice crystals that rupture cell walls causing permanent cell damage and cell death. Ice crystal formation within fruit can rupture juice vesicles, causing fruit to dry out. New leaves, shoots, flowers and fruit are most sensitive to frost. Critical temperatures at which significant frost damage can occur for horticultural crops are shown in **Table 21** and **Table 22**. The number of hours of exposure to sub-optimal temperatures, and the rate at which temperatures increase the following day, will affect the degree of frost damage a plant experiences.

There are two main types of frost: radiation frosts and advective frosts. The most appropriate form of frost control will depend on the prevailing frost types in your area, and the vulnerability of your enterprise to frost damage.

Radiation frosts tend to occur on cloudless nights with little or no wind, when heat is lost rapidly from soils and plants. They are caused by temperature inversions where the warm air from near the ground rises and is replaced by sinking cool air. Cool air flows downhill, such that frosts are more common and severe in low lying areas. Radiation frosts usually start at ground level and slowly rise.

Radiation frosts can be classed as white or black frosts, depending on the moisture conditions when the frost occurs. Under high moisture conditions, ice crystals will form on plants or the ground as a result of condensed water vapour freezing when the dew point temperature drops below 0ºC. This is called a white frost, and is quite visible. Under very dry conditions, plant tissue will freeze without the formation of ice crystals, due to insufficient water vapour being present in the atmosphere for ice to form. This is known as a black frost and can be difficult to identify. Heat is produced as ice forms, so that during a white frost temperatures may plateau for some time, giving the plant some protection and causing less damage than a black frost where temperatures may drop lower. This heat release during ice formation is the reason many farmers use overhead irrigation to protect their crops from frost.

Advective frosts occur when a cold air mass moves into an area displacing warm air, such as when a cold Antarctic air mass moves over the Australian mainland. Frost damage from advective frosts is caused by rapid cold air movement (wind chill) conducting heat away from plants. Advective frosts tend to occur earlier in the night, and affect the upper parts of plants.

Table 21: Critical temperatures (ºC) for frost damage to occur to stone and pome fruit, and grapevines (from Pocock and Lipman, 2002).

Stone and Pome Fruit:	Growth Stage		
	Buds closed, some colour	Full blossom	Small, green fruit
Apple	-2.0	-1.7	-1.1
Apricot	-1.1	-0.6	0
Peach	-3.9	-2.2	-1.1
Pear	-2.2	-1.7	-1.1
Plum	-1.1	-0.6	-0.6
Grapevines: Growth Stage			
Woolly bud	Early bud	Shoots (< 150 mm)	Shoots > 150 mm
-3.5	-1.1	-0.5	0

Table 22: Critical temperatures (ºC) for frost damage to occur to citrus fruits (from Pocock and Lipman, 2002)

Fruit:	Fruit stage		
	Green	Half ripe /button lemons	Ripe
Oranges, grapefruit and mandarins	-1.4 to -1.9	-1.7 to -2.8	-1.7 to -3.9
Lemons*	-1.4 to -2.8	-0.8 to -1.4	-0.8 to -3.3

*Frost damage will occur at -2.8ºC when at bud and blossom stage

Approaches for frost protection

There is little that can be done to protect plants against advective frosts. Plants can be protected from radiation frost through passive or active means, or a combination of the two. Passive methods **(summarised in Table 23)** include careful site selection and farm design, soil and groundcover management, and variety selection and crop management. 'Active' methods for frost protection tend to be activated at the time the frost occurs, and include the use of overhead irrigation, air mixing, foliar sprays and fuel burning **(Table 24)**. Less common methods include the use of fog machines, electrical current or physical covering.

Many active methods are used in conjunction with frost alarms. Frost alarms contain sensors to monitor temperatures and are activated when certain conditions are reached, either notifying the grower or in some cases switching on the management tool immediately. In areas where frosts occur regularly, the use of temperature sensors and frost alarms can ensure optimal management of your frost protection response and prevent wastage of resources.

Irrigation water may be used for frost control passively, in maintaining topsoil moisture, or actively, in the constant application of water during frost events to maintain plant internal temperatures at 0°C. **Table 25** provides some guidance regarding recommended practice in using water for frost control. Water can be an effective and cheap means of frost control, but in water constrained environments it may be worth considering some of the other methods shown in **Table 23** and **Table 24**.

Table 23: Passive methods of frost protection

Protection method	Description
Site selection & design	Avoid growing frost sensitive crops in areas where cold air is trapped by natural topography, vegetation (eg windbreaks) or manufactured obstacles (eg dam walls) that inhibit cold air drainage. Fog can be a good indicator of cold poorly drained areas where radiation frosts may be a problem. Other things to consider when selecting planting sites include soil types (see soil and groundcover management) and aspect (see variety selection and crop management).
Soil & groundcover management	Frost effects can be reduced if the soil can maximise heat storage during the day and then release the heat during the night. Light textured soils do not store or conduct heat as well as heavier textured loam or clay soils. Soils that are of darker colour will absorb more sunlight and store more heat than lighter coloured soils. Moist soils will conduct and store a greater amount of heat than dry soils. Maintaining moist topsoil during the frost season can significantly reduce any yield impact of frosts, however care must be taken to avoid waterlogging and increased risk of fungal disease. Applying water to maintain moist soils during the frost season is most effective if as much of the surface soil area exposed to sunlight is kept moist as possible. A 'light' sprinkler or surface irrigation can be more effective than drip irrigation for this purpose. Soil cultivation should not take place during the frost season, as it affects heat capacity, conductivity and removes heat from soil. A vegetative groundcover will reduce the amount of sunlight reaching the soil, reducing heat storage, and will also slow the transfer of heat from the soil at night. However, inter-row swards/ground covers have many benefits for soil structure. As a compromise, groundcovers should be kept short during the frost season by mowing, slashing or strategic use of herbicides.
Variety selection & crop management	The risk of frost damage is greatest to young leaves, shoots, flowers and fruit. Selection of 'late' varieties of fruit trees or vines can reduce the risk of frost damage because bud burst, blossoming and early fruit growth will occur later in the winter/spring when the likelihood of frost is lower. Similar principles can be used when selecting field crop varieties (eg cereals) by sowing late maturing species. Generally oats are considered most tolerant of frost, followed by barley and wheat with triticale the least tolerant. Another strategy can be to use a range of plant varieties with differing maturity times, or to stagger sowing times, thus reducing the proportion of your farm that will be at risk of frost damage at a particular time. Crop management to delay bud burst will also reduce the risk of frost damage. One approach is planting on south-facing slopes, where daytime temperatures are cooler, which will delay plant development. However, this may affect seasonal production/fruit ripening. Budburst may also be delayed by strategic pruning. Risk of frost damage is greatest close to ground level. Planting on trellises more than 1.5 m above the ground will result in plants experiencing temperatures that are a couple of degrees warmer than those at ground level. For field crops, reducing canopy density by increasing row spacing, reducing fertiliser inputs or seeding rate may reduce the risk of frost damage.

Table 24: Active methods of frost protection that are an alternative to water use

Method	Description	Advantages and disadvantages
Air mixing	During radiation frosts there is an inversion layer of warm air sitting above the colder air at ground level. Mixing the two air layers will reduce the risk of severe frost at the plant's level. This can be done using a wind machine or a helicopter.	Noise pollution is a big concern with the use of wind machines and helicopters. Some local councils have controls on installation of wind machines in built up areas, and there may also be regulations regarding the use of helicopters.
	Wind machines. A single wind machine can protect up to 6 hectares, depending on site conditions, however multiple wind machines will improve the effective area. They are most effective if switched on before a frost occurs (at 1.5 to 0.5°C) and switched off the following morning well after the threat of frost is gone, thus maintaining temperatures rather than trying to increase them above freezing point. If the wind machine does not have sufficient height to reach the inversion layer it can cause more damage than good. Wind machines are believed to create a stable mean increment in air temperature of 1 to 1.5°C. Large, slow moving fans are more effective than fast small fans.	Can be linked to frost alarms, or programmed to start once temperatures drop to trigger levels. Energy requirement and noise issues. High installation/capital costs (starting around $25,000), lowish maintenance costs (minimal labour). If incorrectly positioned can exacerbate frost conditions by drawing down cold air.
	Helicopters. Come at high cost but can be viable depending on frequency of frosts, distance to helicopter base, the size of the are to be protected and the duration and severity of the frost.	High cost; safety issues in areas with large trees, hills, powerlines and if pilot can't see the ground.
Foliar sprays	Use of oil sprays, copper sprays or antifreeze solutions to provide a protective membrane that increase frost hardiness of plants, or eliminate bacteria that would otherwise act as an ice nuclei and cause water in the plant to freeze. Mixed success outside of laboratory situations – allowing sufficient time between application and the frost event can be critical, also requires re-application throughout frost season.	Not really proven in field situations but shows some promise Costly - requires multiple applications Labour intensive Will need to check that the spray is registered for this purpose (with your industry body) and that it will not exceed 'maximum residue limits' or equivalent regulations.
Fuel burning heaters	Fuel such as hay or kerosene is burnt to warm the air, sending up a column of warm air which reaches the inversion layer of similar temperature and density and rises no further. Continual burning results in a gradual warming of the air beneath the inversion layer from top down. Convection currents may also mix air between ground to inversion layer. Balance required in creating heat at rate greater than rate of radiative heat loss, whilst not creating excessive heat resulting in the air breaking through the inversion layer.	Keeps air warmer at crop height Environmental impact from burning fuel (pollution)– may be banned in your area. Labour intensive – works best with many small burners rather than a few large burners.
Fog machines	Used to increase humidity, reducing chance of black frost and possibly frost severity.	Expensive, difficult to control fog mass, not really proven.
Physical covering	Use of insulating material such as cardboard or fibreglass, netting, or greenhouse/ glasshouse to provide warmer ambient temperature conditions	Impractical for large scale plantings Costly, also high labour cost
Electrical current	Used in vineyards: electrical current travels through an insulated cable running along the fruiting wire, warming sap flowing inside the grapevine cane. This protects vine tissues from within the vine.	Some reports suggest can warm sap by up to 5°C. High power costs and probably impractical for large scale plantings

Table 25: Recommended practices for active use of water for frost protection

Principle	· When water freezes on blossoms, fruit, shoots or leaves, latent heat is released. · Provided that the ice continues to form on the target plant tissue, the temperature of the ice will remain at 0°C regardless of the air temperature. · By continually maintaining a wet surface so that ice can form, the plant beneath will be kept at 0°C rather than reaching temperatures at which plant tissue freezes.
Recommended practice	· Over-canopy irrigation is more effective than under-canopy irrigation when it comes to frost control. · Application rates of between 2 and 3.5 mm per hour are sufficient. · Sprinklers should be switched on when temperatures drop to 1°C and not switched off until the next day when air temperatures are well above 0°C and all ice has melted off the shoots/leaves/fruit. · Use a frost alarm and accurate thermometer
Things to watch out for	· If water application ceases during frost period, the ice temperature will drop well below 0°C and cause frost damage. · If the water is switched off too early the next day, the melting ice will extract heat from the plant, causing damage. Evaporation also has a cooling effect that can freeze and damage fruit on frosty or windy mornings, so care should be taken not to switch the system off too quickly. · In heavy soils watering for frost control may lead to waterlogging and increased risk of root rotting diseases such as phytophthora. · During severe or prolonged frosts ice may build up on tree limbs to the point that they break under the weight. · Damp flowers/fruit/foliage can be more susceptible to disease. · Use of watering for frost control could override irrigation scheduling strategies such as regulated deficit irrigation

OPTIONS THAT GO BEYOND FARM BOUNDARIES

The previous sections have dealt with options that can be implemented on your property. In some situations, the terrain and prevailing soil types may increase the costs of these various options to the point that they become unviable. However, by looking beyond your boundary it could be possible to develop options that allow implementation of the Stream Flow Management Plan that are less expensive because the cost will be borne by more than one enterprise. These could include:

- Communal storages
- Cooperative managed water rosters
- Community recycled water schemes
- Construction of a large storage to store irrigation water

Communal storages

In some situations it may be possible to construct an offstream water storage at the boundary of two properties, designed to service both properties **(Figure 8)**. Construction of one large storage will result in less water loss from evaporation than the evaporation from many small storages. Both parties would share the costs of construction and maintenance. The storage would need to be designed by a qualified civil engineer and built by an experienced dam technician. Installation of a depth marker, accompanied by the depth-volume relationships for the storage, is recommended so that both parties could determine the volume of water held in storage at any time.

This option would require a good working relationship between the parties concerned. To avoid later disputes, it would be prudent to develop 'operational rules' considering worst case scenarios (what happens during a severe drought) at the time of storage construction, and to put these down in writing.

To ensure compliance with water licence entitlements, multiple metering points would be required - one on the intake pipe from the stream to the storage, and one on each offtake pipe distributing the water to the respective properties. This option should be discussed with staff from your rural water authority.

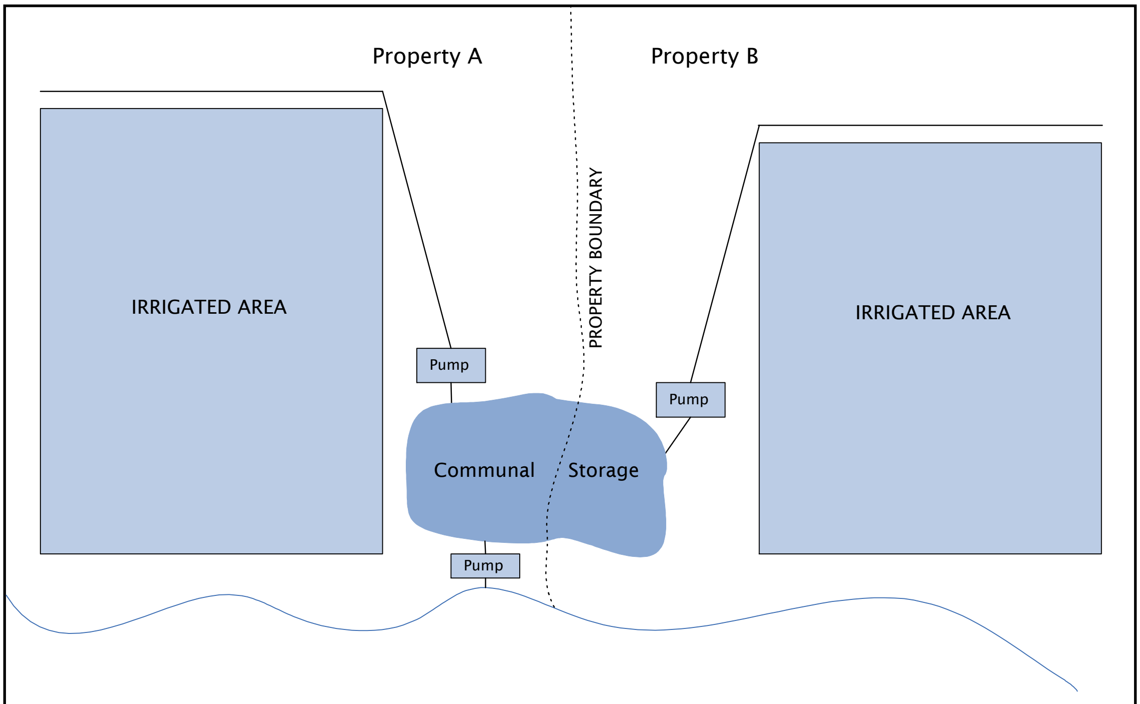

Figure 8: Schematic diagram of a communal water storage shared between two adjoining properties

Cooperative managed water rosters

This approach is about managing irrigation extractions as stream flow becomes scarce, rather than improving security of supply or reducing overall water use.

The Stream Flow Management Plan documents the flow conditions that will trigger your water authority to impose rostering, restrictions and bans on water extraction. However, it is possible for an Irrigators' Cooperative to develop voluntary rosters that are activated before flow conditions reach the triggers set out in the SFMP.

Such a roster would be designed to ensure that all members of the cooperative have equitable access to water, with consideration of the particular requirements of individual crops, each enterprise's total water resources and how the various extraction points could influence downstream flow conditions.

The cooperative would need to establish basic principles for the roster, and then annually update the rules and conditions so that the roster accurately reflected the crop type and irrigated area in production during that year. This approach should be discussed with the responsible water authority. It may be possible to get recognition of the roster so that it is considered in any formal restriction of stream flow extraction in the catchment.

Community reclaimed water schemes

In areas where there is a significant urban population, there is likely to be significant volumes of reclaimed water (treated wastewater) available for use in irrigation. Individual considerations regarding the use of this water were discussed earlier **(see page 19)**. Schemes to utilise reclaimed water, such as piped delivery networks, will be more economic if implemented at a community scale rather than as separate schemes to individual farms.

Development of a community reclaimed water scheme will involve negotiations with the urban water authority responsible for the reclaimed water, your rural water authority, the Department of Sustainability and Environment, EPA Victoria and potentially industry organisations (to ensure any implications for market access are addressed).

Construction of a large storage for controlled irrigation water delivery

Construction of individual off-stream storages will not be practical or cost effective in some catchments due to the prevailing soil types and topography. From a catchment perspective, there may also be significant loss of water through evaporation if a series of small shallow storages are constructed, not to mention the risk of reduced stream flow due to increased overland flow interception.

In unregulated systems with a conflict between irrigation water demand and environmental flow requirements, where construction of individual off-stream storages will be unviable for economic or technical reasons and all other water management options have been exhausted, there may be a case for construction of a large storage that can supplement streamflows to meet irrigation demands. The storage would probably be managed by the water authority, on behalf of the agency responsible for environmental flow implementation.

The operation of such a storage, whether it is constructed on or off the stream, will alter flow patterns in the stream, in effect regulating the flow. Due to the fact that dams have profound ecological impacts and associated high economic costs for construction, operation and maintenance it is unlikely that a dam will be pursued as an option to offset potential changes to reliability of supply. Additionally, Government has placed allocation caps across most Victorian catchments in recognition of ecological stress and over-committed water resources, which includes being a signatory to the Murray Darling Basin Cap.

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- Department of Primary Industries
  - Information sheets about use of groundwater for irrigation are available from the DPI website.
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GLOSSARY AND USEFUL CONVERSIONS

Glossary

Advective frost

An advective frost occurs when a cold air mass moves into an area, displacing the warm air that is present and rapidly reducing air temperatures. This rapid cold air movement or wind chill causes heat to be transferred away from plants or other surfaces.

Agronomic water use efficiency

A measure of the quantity of crop output per volume of water used.

Agronomic water use efficiency = mass of dry matter/volume of water

The volume of water used can be either applied irrigation less runoff, or rainfall plus applied irrigation less runoff. The quantity of crop output is usually harvested yield per unit area. In this review, agronomic water use efficiency is reported using the units kilograms of dry matter per cubic metre of water (kg DM/m^3), which is equivalent to tonnes of dry matter per megalitre (t DM/ML).

Alternate row irrigation

The practice of applying water to every second row in a field, to allow a dry path for traffic and farm operations, and reduce overall water use.

Application efficiency

A measure of an irrigation systems ability to apply a given 'target' depth of water to a field, used to assess what happens during a single irrigation event within a field.

Application efficiency = water stored in rootzone / water supplied to field

The definition assumes water applied is distributed evenly within the field. It is possible to have a high application efficiency even though significant areas of the field are over or under irrigated. Thus it is advisable to include a measure of irrigation uniformity to accompany application efficiency when assessing irrigation system performance.

Aquifer transmissivity

The quantity of water that a given groundwater aquifer can transmit, given by the average hydraulic conductivity multiplied by the average thickness of the aquifer. An aquifer is a layer of underground sediments that holds water and allows water to flow through it.

Available water

The quantity of water held in the soil that can be accessed by plants, usually defined as the difference between field capacity and the permanent wilting point.

Boombacks

Structures used to suspend sprinklers 3 – 4 metres behind the towers of centre pivots or lateral move systems, to reduce the incidence of wheel rutting or bogging. Used in conjunction with half throw or directional sprays, to further reduce the chance of interception of water by the tower or wheels. Can be adapted to suit systems that travel in two directions.

Border-check irrigation

The layout for border-check irrigation (also known as flood irrigation in northern Victoria) consists of a sloping strip of land that is level across the width of the strip, called a bay or border, with parallel raised checkbanks on either side to prevent the lateral flow of water away from the bay. Water is applied in a large stream at the top end of the bay, which then spreads across the width of the bay and advances to the bottom of the bay. The water supply is cutoff when the advance front reaches a predetermined point, to prevent excessive runoff from the bottom of the bay.

Centre pivot

A self-propelled sprinkler system where the irrigation lateral is supported by wheeled towers that rotate in a circle around a pivot point. The speed of travel is usually set by controls on the tower furthest form the pivot point, with alignment controls regulating the movement of the other towers to maintain the designed application pattern. The travel speed and the application rate of the sprinklers control the application depth. Original centre pivots consisted of impact sprinklers mounted upon the top of the irrigation lateral, but most systems now consist of low-pressure sprinklers suspended from weighted drop tubes connected to the irrigation lateral.

Continuous move systems

This category of irrigation systems applies to self-propelling sprinkler systems with a low operating labour requirement, such as centre pivot or lateral/linear move systems.

Deep percolation/drainage/groundwater accessions

The amount of water that penetrates the soil beneath the depth of the rootzone so that it is no longer accessible by the crop, or that seeps from a water storage into the ground, where it is lost to beneficial use. This water then recharges groundwater aquifers or watertables.

Deficit irrigation/regulated deficit irrigation

Deficit irrigation is the practice of supplying less water to the plant than that required to maintain maximum growth, so that some level of plant water stress occurs. Regulated deficit irrigation is the strategic imposition of water stress on a plant to control vegetative growth, increase crop quality attributes and reduce water use whilst maintaining crop yield.

Discharge zone

A discharge zone is a point in the landscape where groundwater levels are above the ground surface, causing the groundwater to seep into the base of rivers, wetlands or flow over the surface soil.

Distribution uniformity

A measure of the uniformity with which irrigation water is distributed to plants within a field. Indices of distribution uniformity generally focus on the least watered quarter of the total field area, comparing the average applied depth in that quarter to the average applied depth for the whole area. This requires sampling of the applied depth of water by an irrigation event at numerous points within a field.

Distribution uniformity = average depth applied in lowest quarter (average of lowest quarter of readings)/ average depth applied to whole field (average of all readings)

Distribution uniformity may also be assessed in terms of the Christiansen Uniformity Coefficient (for sprinkler systems) or through calculation of the coefficient of variation for performance of emitters (for micro irrigation systems such as drip and subsurface drip).

Drip irrigation

An irrigation system where water is delivered directly to small areas adjacent to individual plants through emitters placed on a water delivery line. Water drips from low flow rate emitters onto the soil. Most drip systems are based on drip tape, which is plastic hose with emitters built into the walls or seams of the tape at a predetermined spacing.

Drop tubes

Flexible plastic tubing attached to manifolds on the lateral of a centre pivot or linear move system, from which sprinklers are suspended, to reduce the distance of the sprinklers from the crop or soil surface and so minimise wind distortion or evaporation losses.

Electrical conductivity

Electrical conductivity is a measure of how well a material accommodates the transport of electrical charge. The electrical conductivity of water is determined by the levels of dissolved salts present in the water. The dissolved salts can include sodium, calcium, potassium, magnesium, chloride, sulphate, carbonate and bicarbonate. An increase in the amount of dissolved salts in the water will increase both its electrical conductivity and salinity by a known amount, so that measurement of electrical conductivity can be used as a surrogate measurement of salinity. Electrical conductivity is the reciprocal of electrical resistance, and is measured in the amount of conductance over a set distance.

Emitters/drippers

A device used in drip and subsurface drip irrigation to control the amount of water applied to the field from the water supply line. An emitter releases water at a set flowrate, usually between 0.5 to 4 litres per hour. Emitters may be pressure compensating, to allow for fluctuations in the system operating pressure that may arise from topography.

Environmental Water Reserve

The share of water resources set aside to maintain the environmental values of a water system and other water services that are dependent on the environmental condition of the system.

Evaporation

The process of transforming liquid water into a gaseous state, using considerable energy. Can only occur if water is available and the humidity of the atmosphere is less than the humidity of the evaporating surface.

Evapotranspiration

The combined transfer of water to the atmosphere through the processes of evaporation and transpiration, which is the loss of water from plants through stomata on leaves. Transpiration is usually a passive process, controlled by atmosphere humidity and soil moisture, but some plants can control their stomata opening to reduce moisture loss. Evapotranspiration is controlled by energy availability, humidity gradients, wind speed above the soil surface, and water availability.

Fertigation

The practice of applying fertilisers through an irrigation system, by mixing soluble forms of nutrient with irrigation water, usually in small regular doses. This removes the need to broadcast fertiliser on the soil surface, reducing nutrient loss through surface runoff or volatilisation, and may improve plant uptake of the nutrient. Most fertigation systems are used to apply nitrogen, but they can also be used for the supply of phosphorus, potassium, sulphur, zinc and iron.

Field capacity

A state following saturation of soil, where excess water has drained from large pore spaces due to gravity, but water still coats soil particles and organic matter and fills all small pore spaces. The moisture content representing field capacity is usually defined as the moisture content at a matric potential of –10 kPa. At saturation, water fills the pore spaces. At field capacity, air occupies the large pore spaces while water fills the smaller pore spaces. At permanent wilting point (matric potential of -1500 kPa), plants cannot extract additional water from the soil.

First flush

Contaminants and excess nutrients that have deposited on the soil surface may become dislodged under heavy rainfall and accumulate in the initial surface runoff in large concentrations. This "first flush" of water into receiving water bodies will contain higher levels of contaminants than subsequent runoff. Ideally drainage from your property should be managed so that the first flush is captured on-site.

Fixed or solid set sprinklers

These systems consist of a network of mainline and lateral pipes, with a grid of sprinklers mounted on the laterals. They can be permanent, with the laterals and mainlines buried, or portable, able to be disconnected and removed prior to harvest. Portable set sprinklers are often used for crop germination. The systems have minimal labour requirements during the irrigation season, with some labour at the start and end of season for portable systems. A high application efficiency and distribution uniformity is usually achievable.

Furrow dykes

Small mounds of earth mechanically installed in furrows, to create mini storage basins in front of each dyke. Used in conjunction with LEPA systems to manage runoff generated by high application rates, improving infiltration and distribution uniformity across the field.

Greenhouse gas

Gases that contribute to an enhanced greenhouse effect altering climate conditions, including carbon dioxide, methane and nitrous oxide.

Groundwater Management Plan

Similar to a Stream Flow Management Plan, a Groundwater Management Plan is designed to balance consumptive water use with the provision of an Environmental Water Reserve to maintain groundwater levels that sustain a set of agreed ecological objectives for that aquifer. It determines the current and likely levels of consumptive water use from the aquifer, defines the required Environmental Water Reserve, then clarifies levels of water security, rules for rostering, trading and granting of additional licences. A Groundwater Management Plan is developed with community input.

Half throw or reduced flow rate sprinklers

Half throw, or part circle sprinklers, apply water to less than 360° of the possible irrigated area, reducing the application of water to non-target areas or the irrigation infrastructure. Reduced flow rate sprinklers may be selected for use close to the towers of a centre pivot or linear move, so that less water is released to reduce the risk of interception or wheel-rutting.

Heavy metals

A metallic chemical element that has a high density and is toxic or poisonous at low concentrations is called a heavy metal. Examples include mercury, arsenic, cadmium, lead and chromium. The concentration of heavy metals tends to accumulate in living organisms over time because they are taken up by the body/plant more readily than they break down or are excreted.

Hydrocarbons

A type of organic compound consisting of carbon and hydrogen atoms, which can be natural or modified. The reaction of hydrocarbons with nitrogen oxides in the presence of sunlight leads to the formation of smog.

Impermeable

This relates to the hydraulic properties of the soil. A soil is considered impermeable if it has a very low saturated hydraulic conductivity, such that very little water can infiltrate into and through the soil.

Infiltration rate
Infiltration is the process of downward movement of water into the soil from the soil surface. Two infiltration properties of interest to irrigation are the infiltration rate, and the cumulative infiltrated depth, which are both functions of time. Infiltration behaviour is affected by soil texture. Infiltration in sandy soils is driven by gravity. For medium textured soils such as loams, infiltration is initially dominated by suction gradients until a steady state rate dominated by gravity forces is reached. In heavier cracking clays, the initial infiltration is driven by crackfill processes, which can constitute a large proportion of the cumulative infiltrated depth, with the final gravity-dominated infiltration rate quite low in comparison. For most red brown earths in northern Victoria, the infiltration behaviour of the soil is dominated by the less permeable B horizon.

Instantaneous application rate
The rate of water application to a finite area of land as the machine passes over that area, measured in mm/hr. Low pressure sprinklers or sprays that water a small area will have a higher instantaneous application rate than a higher pressure sprinkler with a larger area of throw.

Irrigation scheduling
The process of deciding when to irrigate and how much irrigation water to apply at that irrigation.

K-Line
A sprinkler system consisting of a series of pods containing small sprinklers attached to a line of low density poly-pipe, that is fixed to a mainline riser at one end. The system is moved manually to its next position using a four wheel motorbike or similar device. The system is designed to use low pressure and is tailored to the dimensions of the field. However, as a manual shift system it can have problems with application uniformity.

Lateral or linear move
A self-propelled irrigation lateral using a tower support system and guidance control similar to a centre pivot, but designed to operate on rectangular fields. Water is supplied to the lateral either from an open ditch, or by a flexible rose connected to a mainline. A wide range of sprinklers and nozzles may be used, over a wide range of pressures. Similar to centre pivots, the use of sprinklers attached to drop tubes suspended from the main lateral is becoming prevalent.

Leaching fraction
An amount of additional irrigation water above the crop water requirement applied in order to maintain an acceptable rootzone soil salinity. The amount required is a function of the salinity of applied irrigation water, current soil salinity conditions, the desired rootzone salinity and the likely rainfall in the area.

Low Elevation Spray Application (LESA)
LESA systems consist of low pressure spray sprinklers (fixed or spinners, rotators and wobblers) suspended from drop tubes attached to a centre pivot or linear move, below the crop canopy and usually 0.3 to 0.6 m above the ground. Application rates in LESA irrigation are generally lower than those of LEPA systems because the water is applied to a larger area.

Low Energy Precision Application (LEPA)
LEPA is a low pressure application package for centre pivots and linear moves, where bubbler or drag socks suspended from drop tubes apply water directly to the soil surface at high application rates. This minimises evaporative losses but increases the incidence of runoff, so that the use of furrow dykes or tillage basins is required to allow the water to pond and infiltrate the soil, if high application efficiencies and uniformities are to be obtained. .

Low pressure moving plate sprays (rotators, spinners and wobblers)
Low pressure spray sprinklers have a fixed head, with a deflection plate that creates a spray by deflecting the water jet as it exits the nozzle. The deflection plate can have a convex, concave or flat shape, and be smooth, which causes the water to leave the plate as a mist-like spray, or grooved, which creates tiny streamlets. Moving plate sprinklers minimise operating pressure while increasing application uniformity, and can be used on a wider spacing than low pressure fixed plate spray sprinklers. Moving plate sprinklers decrease water application rates by increasing the wetted area. Compared to medium groove serrated or smooth plates, “rotators”, “spinners” and “wobblers” reduce the number of water streamlets and increase both drop size and the throw distance. Increasing drop size reduces susceptibility to wind drift loss.

Matric potential
A measure of the difficulty for plants in extracting water from soil. A fully saturated soil has a matric potential of 0 kPa, with the matric potential increasing as water availability decreases and water is more firmly attached to soil particles. It is reported as a negative pressure.

Mid Elevation Spray Application (MESA)
MESA systems consist of low pressure spray sprinklers (fixed or spinners, rotators and wobblers) suspended from drop tubes attached to a centre pivot or linear move, just above the crop canopy and usually 1.5 to 3.0 m above the ground.

Nutrient leaching
The downward movement of dissolved nutrients through the soil profile with percolating water. Nutrients leached below the rootzone can potentially accumulate in or contaminate groundwater supplies.

Nutrient loading
The quantity of nutrients contained within a given volume of water or soil.

Observation bores
An observation bore is a bore that is used to monitor the level and fluctuation of shallow groundwater tables. A measuring tape is used to measure the distance to the water surface at regular time intervals (weekly or monthly). This is done either by listening for the plop as the end of the tape hits the water surface, or by attaching a whistling device (such as a fox whistle) that whistles when it hits the water surface.

Opportunity time
The time that irrigation water has to infiltrate soil. For surface irrigation systems, this is the difference between the time that the advance front of water reaches a point, and the time that all surface water has drained away from that point following the shutting off of the water supply. For a continuous move sprinkler system, this represents the total time that a particular point in the field was being watered by the sprinkler, through to no water being visible on the soil surface at that point.

Partial rootzone drying
An approach to irrigation scheduling where part of the rootzone is fully irrigated for a predetermined time or number of irrigations whilst the other portion of the rootzone is allowed to dry out, then the watering regimes are switched so the dry portion is watered and the "wet" portion dries out. This is designed to manipulate plant processes to minimise water loss or reduce overall water use. Partial rootzone drying is still under investigation for a number of horticultural industries.

Permanent beds
A permanent bed system consists of raised beds that are retained and reused after each crop, with superficial cultivation between crops to maintain bed shape. This maintains soil structure and allows for the accumulation of organic matter, whilst increasing the amount of well drained topsoil available for plant growth.

Permissible Annual Volume
The total volume of water that can be extracted in a year via licences as authorised by the Minister for Water. This can be applied to a surface water catchment, or a groundwater aquifer.

Pivot point
The fixed point anchor of a centre pivot irrigation system, at the centre of the irrigated area, which supplies water to the pivot lateral from the irrigation mainline. This is the point that the machine rotates around.

Radiation frost
A radiation (or inversion) frost tends to occur on cloudless nights when there is little wind, and are caused by temperature inversions. This is when warm air from near the ground rises and is replaced by sinking cool air. Cool air flows downhill, so this type of frost is more common and severe in low-lying areas. These frosts start at ground level and slowly rise. The visibility of the frost, that is whether it is "white" or "black", is determined by the level of moisture in the air at the time. White frost occurs under moist conditions, when water is available to settle on plant leaves and freeze.

Runoff/tailwater
When water is applied to the soil surface at a rate that exceeds the soil infiltration rate, it ponds on the surface. If there is a slope to the field, this water will become surface runoff, forming a stream that follows the gradient of the field and drains to the lowest point. Runoff water can become a pollutant by carrying with it sediment, fertilisers and chemicals. If runoff water is not captured on farm by a reuse system, it may discharge into the nearest water body.

Salinity
Salinity is a measure of the amount of dissolved salts present in water. It can be measured directly using a hydrometer, a refractometer or gravimetrically (by determining the total dissolved solids), or indirectly by measuring electrical conductivity. Salinity is considered a problem when the quantity of salts present reaches a level that adversely affects the growth of plants or animals. This could be through direct application of water of high salinity to plants/animals, by gradually building up levels of salts within the plant rootzone or in receiving water bodies through the application of saline waters, or through rising groundwater levels where the groundwater is of high salinity.

Seepage
See deep percolation.

Sideroll
A sprinkler system where the irrigation lateral is mounted on wheels, forming the axle of the wheels, with impact sprinklers connected to the top of the lateral generally at the midpoint between two wheels. The lateral is usually connected at one end to a riser in the field by a length of hose. A drive unit at the centre of the lateral is used to move the Sideroll from one set to the next, but needs to be switched on manually. Side roll systems have high labour requirements and generally lower application efficiencies and distribution uniformities than continuous move or fixed set sprinklers.

Sodicity
An excessive concentration of sodium within a soil, leading to soil structural problems (such as decreased soil stability, slaking and dispersion, surface sealing, reduced infiltration capacity). The presence of sodicity is assessed by calculating either the Exchangeable Sodium Percentage (ESP) of the soil, or by determining the Sodium Adsorption Ratio (SAR).

Soil crusting
When surface soil particles are dispersed as a result of heavy rainfall or irrigation droplet impact, becoming dis-aggregated from the rest of the soil, they can realign and become packed into an impermeable seal on the soil surface. This reduces future infiltration of water, and can cause crop emergence problems.

Soil hydraulic properties
A soil's hydraulic properties determine how the soil will behave under irrigation. Important hydraulic properties include the final infiltration rate, saturated hydraulic conductivity and water holding capacity. These will determine the rate at which water should be applied to prevent runoff or excessive drainage, and give some guidance as to how frequently water will need to be applied, given the amount of water the soil can store.

Spatial variation
Something that is not uniform across a given space. For example, a soil property that varies with distance from a given point.

Stream Flow Management Plan
A Stream Flow Management Plan (SFMP) is designed to balance consumptive water use with the provision of an Environmental Water Reserve to maintain stream flows that sustain a set of agreed ecological objectives for the stream system. As part of its development, an assessment of current and likely levels of consumptive water use from the stream is undertaken, along with scientific studies to define the desired ecological objectives for the catchment and the Environmental Water Reserve necessary to meet those objectives. The SFMP is developed with community input, and clarifies levels of water security, rules for rostering, trading and granting of additional licences for the catchment.

Subsurface drip irrigation
An irrigation system where water is delivered directly to small areas adjacent to plants through emitters built into the walls or seam of drip tape, a plastic hose that is buried at a depth within the crop's rootzone. Water drips from the low flow rate emitters into the soil and is distributed through the soil around the emitter by capillary action.

Surge or surge flow irrigation
Developed in furrow systems, this technique of managing surface irrigation involves pulsing the application of water, as compared to the usual practice of applying a continuous wave of water until it has reached a desired cutoff point. The irrigation is managed with cycles of watering time followed by periods where no water is applied, allowing recession to occur. This alters the infiltration behaviour of the soil so that subsequent surges of water pass over the wet areas without excessive seepage of water, leading to a more uniform application along the entire furrow length.

Sustainable yield
The amount of water that can be extracted from a groundwater aquifer, that is replaced through groundwater recharge within a relatively short timeframe, so that overall water levels in the aquifer are maintained at their current level. This is the opposite of groundwater "mining", which occurs if rates of extraction are much greater than the replenishment rate, leading to a reduction in water availability.

Total dissolved solids
Total dissolved solids (TDS) is used as a measure of the salinity of water. It is calculated as the weight of the total dissolved salts within a given volume of water, usually measured in mg/L or parts per million.

Travelling irrigators/guns
In these systems, water is supplied through a flexible hose to a high volume, high pressure sprinkler head or boom mounted on a trailer. Before irrigation, the trailer is dragged out to a start point, and then during the irrigation the trailer is winched back through the field by the hose, which is progressively wound on a large drum. The reel is operated by either an engine or a water driven mechanism. These systems are suited to supplemental irrigation, but seldom have high uniformity and the pattern of application is easily distorted by wind.

Unregulated catchment
A catchment that contains a river system where no major dams or weir structures have been built to assist in the extraction or supply of water.

Variable rate irrigation
A developing technology, also known as precision or site specific irrigation. Use of centre pivot or lateral move sprinkler to deliver varying amounts of water to different sections of the field, accounting for differences in topography and soil properties. This allows the optimum amount of irrigation water to be applied without ponding, runoff or under-irrigation. The systems work by varying the travel speed of the machine, or by switching between sprinkler nozzles designed to apply different flow rates, or both.

Water holding capacity
A measure of the amount of water a soil can store to supply plant water requirements, largely determined by the pore space created by soil texture and structure.

Water use efficiency
A generic label for performance indicators used to study water use in crop production. Can cover application efficiency, agronomic water use efficiency, and production system water use efficiency, which examines efficiency of production of farm outputs in terms of water inputs. Economic water use efficiency, which assesses the dollar return per megalitre of water used, is often used in comparisons of irrigation industries.

Waterlogging
Waterlogging occurs when the soil is saturated and there is an excess of water in the rootzone so that plants cannot obtain oxygen through the roots. Waterlogging can kill plant roots, reducing the uptake of oxygen, nutrients and water, or lead to the development of shallow root systems, which reduces the future uptake of oxygen, water and nutrients when the soil dries out. Waterlogging may occur after irrigation or in situations where there are shallow water tables.

Wetting front
The advance front of water (irrigation or rainfall) moving through the soil profile, ie the edge between dry and wet soil. The use of wetting front detectors can show when water has infiltrated to a certain depth, to guide management of individual irrigation events.

Conversions

Water

1 inch = 25.4 mm

1 m = 1000 mm

1 m^3 = 1000 L

1 ML = 1000 m^3

1 ML/ha = 100 mm

Salinity

1 dS/m = 1000 µS/cm

1 EC unit = 1 µS/cm