

# 1.6 Managing storages and channels

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## Key points

- Storages are the largest source of water loss on most irrigated cotton farms.
- Measurement is critical for determining storage losses. Even if you think your losses are low, this information is very important for water budgeting and benchmarking.
- Storages can differ from their design volume by 20% or more. Storage surveys are very useful to verify storage capacity and storage curves.
- A range of solutions for minimising evaporation and seepage can be employed ranging from management options to structural solutions.
- The evaporation and seepage ready reckoner can be used to determine the cost effectiveness of different solutions

Whole farm water use efficiencies are reduced by excessive evaporation or seepage losses, or both, while water is being stored in dams, conveyed around the farm, applied to fields or returned to the storage. This topic considers the opportunities for measuring evaporation and seepage losses from storages, channels and reticulation systems, investigating potential solutions for remediating excessive losses and assessing whether these solutions can be economically applied.

## Determine the extent of losses

The first step when considering ways to minimise losses from storages is to get as much information about the actual loss that is occurring. This is absolutely necessary in order to determine the best possible solution, how effective it might be and how cost effective it is to implement. Much of this information is also valuable for other purposes in farm water management and planning.

## Regular recording of water depth and volume

Regularly recording water depth and volume provides excellent information for general water management but can also highlight potential issues and changes in storage performance over time. An up to date storage volume record can improve forward decision making about planting area or how to best use the available water during the irrigation season. Accurate storage volume data is required when preparing water budgets and regular data is required to be able to update budgets throughout the season.

Importantly for understanding losses, storage volume information allows you to perform a whole farm water balance which can reveal how significant storage losses are as a proportion of all on farm water loss. Regular information which can provide you with data on the volume of water extracted from and returned to storage can also allow you to calculate storage efficiency.

### Whole farm water balance

A whole farm water balance is a procedure by which the water inputs and outputs of a farm are compared so that losses can be determined. Recently developed tools such as [Watertrack Divider™](#) allow the losses from different components of the irrigation system (storages, channels, drains and fields) to be determined. Further information on whole farm water balance can be found on page 51 of the [2012 Australian Cotton Production Manual](#).

Such an assessment can reveal the significance of storage losses as a component of all on-farm water use which can help to prioritise areas where effort to reduce losses should be targeted. Measures of storage volume are required for these calculations.

An assessment of water losses for 30 farms in the Queensland Murray Darling Basin for the 2009-10 and 2010-11 seasons showed that storages were the greatest source of loss. Whilst the average storage loss was 20% (Figure 1.6.1), individual farms had losses ranging from about 5% to 45% (Figure 1.6.2). A full summary of results is available in the publication [Whole Farm Water Balance: Summary of Data 2009-2011](#).

Figure 1.6.1 – Average water use for 30 farms in the QMDB 2009-2011.

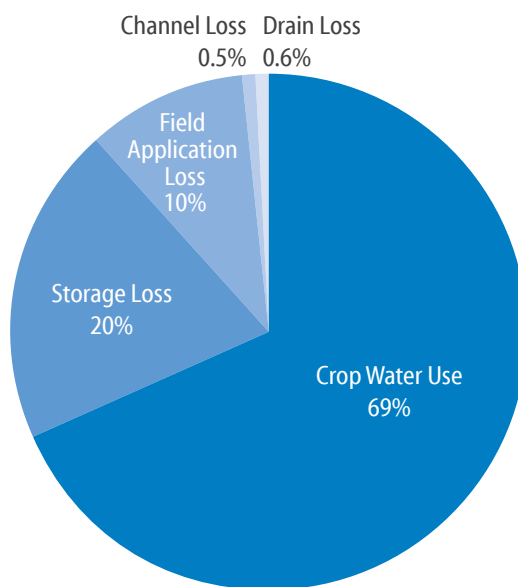
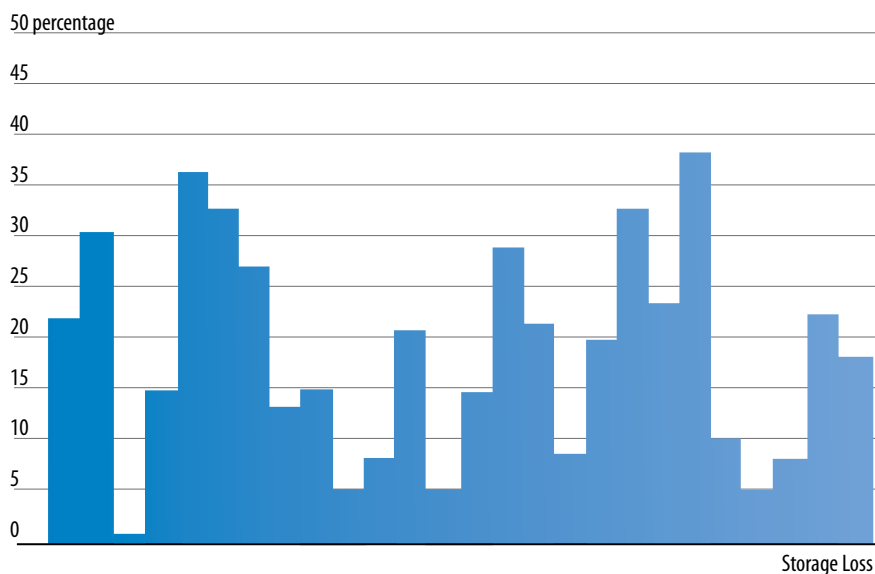


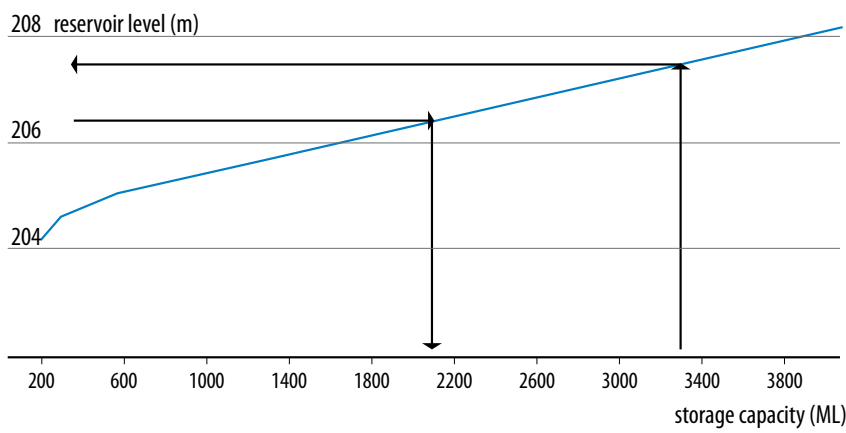
Figure 1.6.2 – The range of water lost in storage for individual farms in the QMDB 2009-2011.



### Measurement techniques

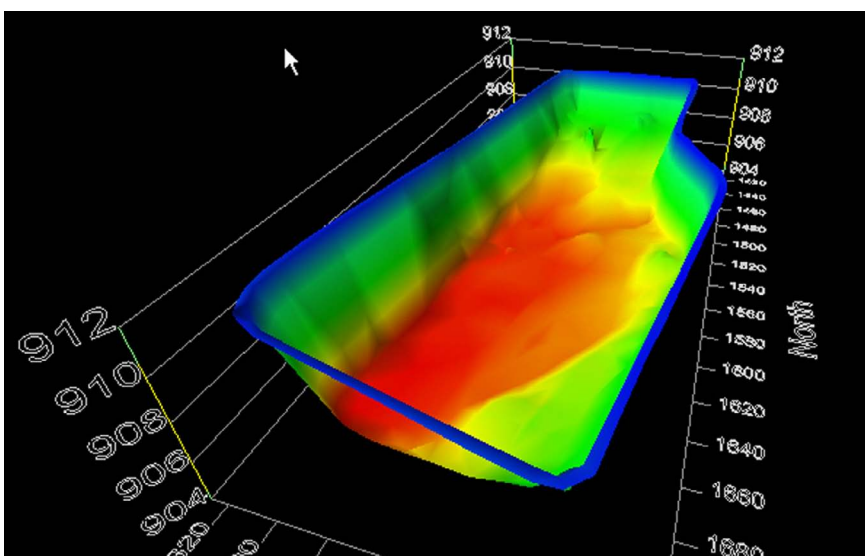
Most storages have gauge boards which give a visual indicator of storage depth. Gauge boards can provide a measure of the amount of water in storage, although converting this water depth to a volume requires a storage curve. Engineers produce storage curves for each dam they build. Storage curves relate the volume of water stored or storage capacity in mega litres to the height of the water in the dam. The height of the water is usually recorded as its height above sea level. Figure 1.6.3 shows how a gauge board level can be converted to a volume (and vice versa) using a storage curve.

Figure 1.6.3. Flow meters with gauge boards and storage curves



Whilst manual recording of gauge board levels can provide some information, regular information (for example daily or hourly) is usually required to determine the inflow and outflow volumes needed to calculate storage efficiency. Alternatively, flow meters may be able to provide this information, although they do not provide a measure of the volume of water in storage at any one time.

Figure 1.6.4 – An example of a modern storage survey.



Electronic storage meters (such as the [Irrimate Storage Meter™](#)) have become more popular in recent years as they provide a real time measure of the volume of water in storage and can be fitted with telemetry systems so that this information can always be available in the farm office. This information can be used for whole farm water balance, real time water budgeting and calculating storage efficiency.

### Storage survey

A storage survey is another particularly useful piece of information to better understand your storage. Usually the storage curve will have been determined when the storage was originally designed. In recent years, advances in surveying techniques have allowed much more detailed information to be obtained in shorter timeframes and the number of growers obtaining storage surveys has increased. Storages can even be surveyed when they are full of water!

However many of these storage surveys have revealed inaccuracies in the original information, with the actual volume of some storages having a [difference of more than 20%](#) when compared to the existing information used by the grower. This has significant implications for management decisions and water budgeting, where such inaccuracies could mean that water runs out prematurely or water that could have been used productively is not required. Furthermore, such errors could be masking substantial storage losses.

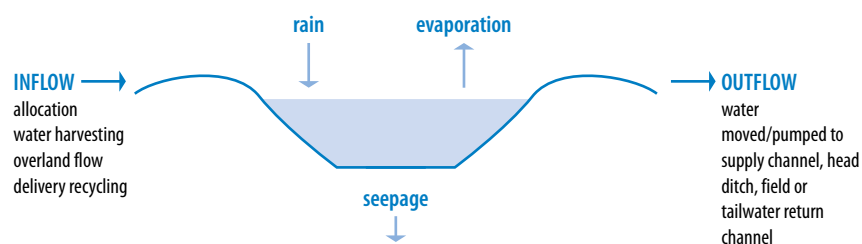
## Storage Efficiency

Like other measures of irrigation efficiency, storage efficiency relates the amount of water used to the amount of water supplied (stored) over a period of time.

$$\text{Storage Efficiency} = \frac{\text{water used from the storage}}{\text{water stored in the storage}} \times 100$$

The same calculation can also be used to determine the efficiency of channels and return systems. Because these systems usually have water being added and removed regularly, obtaining the actual water used and stored over a period of time can be difficult. This typically requires regular readings from flow meters or a regular measure of total storage volume to be able to determine the water inflows and outflows. All of these systems have a similar set of inputs and outputs, as shown in Figure 1.6.5.

Figure 1.6.5. Components of the water balance of storages, channels and return systems



Source: Dalton et al. 2002

From this, it can be seen that the information required to calculate efficiency in the equation above is as follows:

$$\begin{aligned} \text{Water used from the storage} &= \text{Water outflow} - \text{tailwater return} \\ \text{Water stored in the storage} &= \text{Starting volume} + \text{water inflow} + \text{rainfall} - \text{ending volume} \end{aligned}$$

If all of the required parameters have been accurately measured, the difference between the two terms will account for the storage losses (seepage and evaporation).

Dalton (2000) demonstrated how the duration of water storage can affect storage efficiency with measurements on a storage with two cells that were both filled at the start of the season. Water from one cell was used early in the season for pre-irrigation and had a storage efficiency of 85% while the other cell was used for later irrigations and had a storage efficiency of 55%. Channel efficiencies should be higher than for dams because water is not usually stored for long periods of time before it is used and this reduces the opportunity for evaporation and seepage to occur.

## Seepage and evaporation measurements

Regular storage volume data and a better understanding of storage capacity are particularly useful for better water management and to identify the magnitude of storage losses within the context of all farm water use. However, if this information suggests that options to reduce storage loss should be investigated, it is important to know how this storage loss is occurring, and therefore what type of action would be most appropriate.

Storages can lose water through either seepage or evaporation, but it has historically been difficult to determine what proportion each contributes to the total loss. In practice, this has often been achieved by estimating evaporation losses (for example by using  $ET_0$  or pan data) and subtracting this from the total water loss to provide an estimate of seepage. [The Ready Reckoner Monthly Evaporation Calculator](#) can be used for this purpose.

However it is now known that evaporation from individual storages can vary due to local characteristics such as the shape and dimensions of the storage or the nature of the surrounding area, which can influence the fetch (the upwind conditions). Other characteristics such as the temperature of the water will also affect evaporation. This means that evaporation estimates should be multiplied by a dam factor ( $k_{dam}$ ) before they are accurate for a particular storage, although unmodified evaporation data is still better than nothing.

Recent work has been undertaken by a number of organisations across Australia to better understand the nature of seepage and evaporation losses. From some of this work, [equipment and data analysis techniques were developed](#) to obtain these measurements in a more practical way. This is now provided as the [Irrimate™ Seepage and Evaporation Meter](#).

It should be noted that existing research techniques, such as atmospheric flux techniques (for measuring evaporation) or infiltrometers (for measuring seepage), rely on point source measurements and do not give a value for the entire storage. The Irrimate™ Seepage and Evaporation Meter measures losses from an entire storage, which is especially important considering most seepage loss tends to occur in discrete locations rather than uniformly across an entire storage.

Once you have measures of evaporation and seepage, they can be used to:

- Improve the accuracy of detailed water budgets and whole farm water balances.
- Compare losses from different storages to identify which (if any) require attention.
- Determine whether seepage or evaporation is the main issue that to be addressed.
- Determine the cost effectiveness of potential solutions.

The use of this data for determining the cost effectiveness of different solutions is covered later in this chapter.

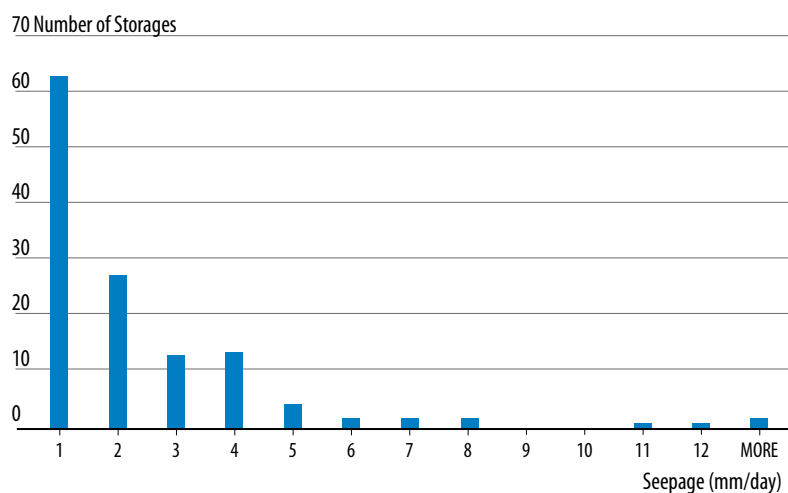
However [this case study](#) demonstrates how valuable this information can be for water budgeting. In this case, the grower undertook a water budget and estimated that the seepage loss from this storage was 1 mm/day. When measured, the actual seepage loss was 3.5 mm/day. Although this loss is still reasonably low, it meant that the water budget was underestimating the actual seepage loss by 50 ML per month!

For storages where seepage losses are very high (greater than about 10 mm/day), an initial rough estimate of losses may still be useful to determine whether the seepage loss is so high that you should consider immediate action (possibly even removing the water from the storage as soon as possible). Manually measuring the total storage level change over a period of a few weeks and subtracting the evaporation data for this period can provide you with an estimate of seepage. However an accurate measure is still required to determine the cost effectiveness of potential solutions with any certainty. Furthermore, losses less than 10 mm/day are still significant, but are much more difficult to measure with any accuracy. As an accurate measurement can take about 5 weeks to obtain, the longer the delay in deploying this equipment, the longer water must remain in the storage.

### Existing Industry Data

The Irrimate™ technology was used to [measure seepage and evaporation losses](#) from 137 storages across the cotton industry from 2009 to 2011. The storages ranged from 75 ML to 14000 ML in volume and had depths of water at the time of measurement from 1 metre to 9 metres. Seepage for most storages was generally quite low, with 88% of storages having a seepage rate of less than 4mm/day (Figure 1.6.6). Growers were asked to estimate their seepage rate as low, moderate, high or very high prior to the evaluation taking place. Only 80% of growers were able to accurately estimate their seepage rate within these broad bands. This highlights the value of accurately measuring seepage to ensure that your whole farm water management and budgeting is accurate.

Figure 1.6.6 - Number of storages measured with seepage of different rates



Evaporation was also measured and a dam factor ( $k_{dam}$ ) was developed for each storage which related the actual evaporation from the storage to the predicted FAO56  $ET_0$  value at each location obtained from the SILO service.

$$\text{Daily evaporation (mm)} = k_{dam} \times \text{SILO Daily } Et_0 \text{ (mm)}$$

Dam factors ranged from around 0.7 to around 1.3 (Figure 1.6.7), indicating that individual storages could have quite different evaporation rates. This would be due to various individual characteristics such as the water temperature, the orientation of the dam to prevailing winds and the presence of windbreaks, amongst others. This potential annual evaporation ranged from 1 to 2 metres per year (Figure 1.6.8) depending on the storage location (high evaporation environment vs. low evaporation environment) and the individual dam factor. The average potential evaporation was around 1.5 metres per year.

Figure 1.6.7 - Number of storages with different dam factors ( $k_{dam}$ )

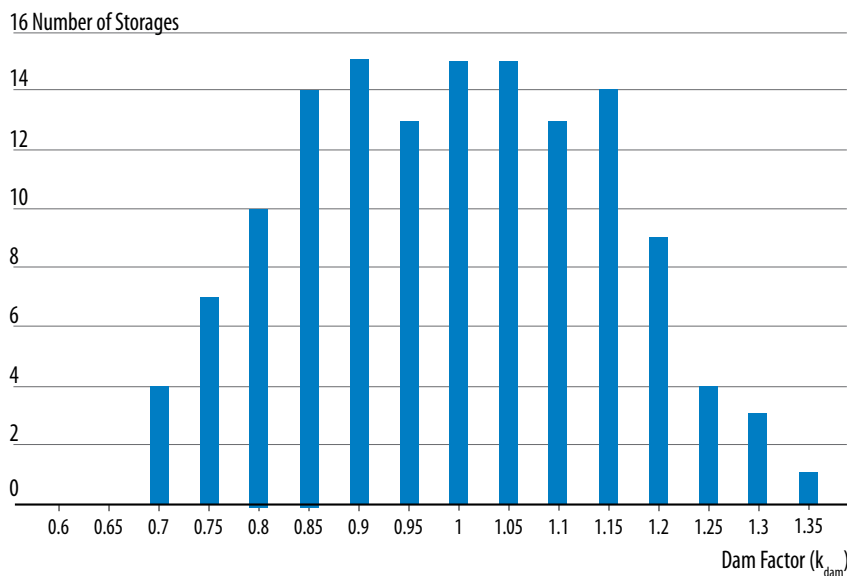
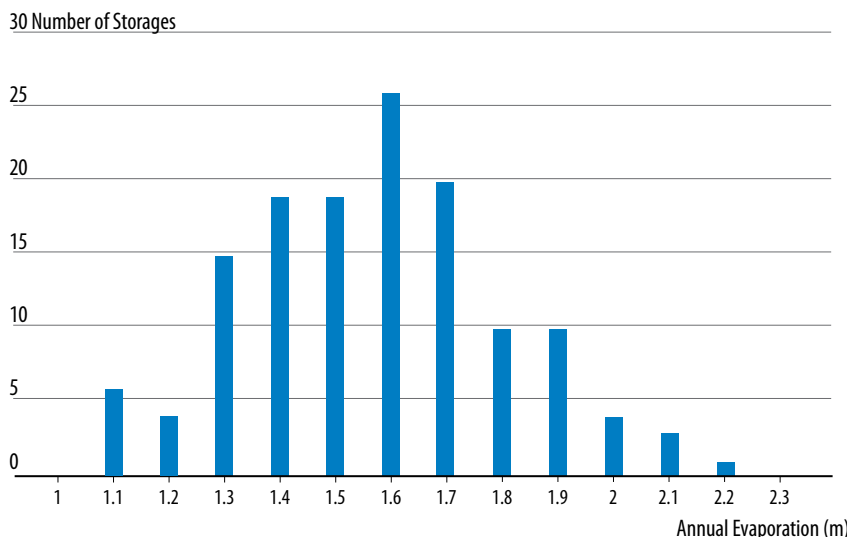


Figure 1.6.8 - Number of storages with different potential annual evaporation



### Identify potential solutions

If you have undertaken the various measurements outlined above, you will be in a good position to determine whether or not the losses from your storage require attention. Whether or not you should actually take action will ultimately be determined by the cost effectiveness of particular solutions; methods for determining cost effectiveness are outlined later.

If you have undertaken a whole farm water balance, there are unfortunately no hard and fast rules regarding how much storage loss should be expected, except to say that lower is obviously better.

The proportion of water lost in storage will vary depending upon the nature of your water supply. Those growers who need to store water for long periods of time will most likely have a greater proportion of loss than growers who reduce their storage volume quickly. The best way to use this information is to compare with other growers who have similar operations to your own.

If you have seepage and evaporation measurements, you may be able to compare your results to those obtained from the industry study above. In terms of evaporation, the longer you store water, the more cost effective it will be to apply an evaporation mitigation strategy. Recent investigations have shown that some strategies such as dividing a storage into cells can be very cost effective as discussed below.

In terms of seepage, the seepage rate at which it becomes cost effective to take action will vary significantly depending upon how often your storage contains water, the area over which seepage is occurring, the effectiveness of potential remedies and the cost of these remedies. Table 1.6.1 contains a very rough guide

Table 1.6.1 – A rough guide to storage seepage rates.

Seepage Rate	
Above 3 – 4 mm/day	If you store water fairly regularly, it may be cost effective to undertake remediation works, provided the seepage is occurring in a confined area and the potential remedies provide effective seepage reduction. If this is not possible, at least having a precise measure of your seepage rate will be invaluable for water budgeting.
Above 6 mm/day	Numerous seepage remedies are likely to be cost effective, provided you can identify where the seepage is occurring and the applicable remedies are able to provide effective reduction in your circumstances.
Above 8 mm/day	You really need to take action. Most remedies will be cost effective. You will still need to be able to identify where the seepage is occurring and have conditions under which the mitigation solution will be effective. At these seepage rates it is probably advisable to use the storage as little as possible.

The following sections will outline the potential options that may be considered and their likely effectiveness. The cost effectiveness of the most suitable option, and therefore the final decision about how to act, is covered in the final section.

## Management solutions

Perhaps the lowest cost solution available is to focus on managing the water that you have. The flexibility you have will be limited by your farm characteristics, but management options would include combining water from multiple storages into a single storage, moving water from a partly full large storage into a smaller storage or applying water to fields in preparation for the next season's crop. Each of these options is aimed at reducing the surface area of water that is available to be evaporated or to be lost to seepage.

A simple calculator which predicts the likely monthly volume of evaporation and seepage loss for a given surface area is available on the [Evaporation and Seepage Ready Reckoner](#) website. It should be noted that this calculator does not account for individual dam factors and provides only an estimate of evaporation based on historical averages.

### Moving water

Moving water between storages might be attractive when you have small amounts of water in two or more storages, or when you are holding water in a storage which is larger or has higher losses than an alternative storage. When you move water between storages, you should consider:

- The water required to saturate the floor of the storage you are moving water to. If the floor of this storage is particularly dry, you could lose up to 2.5 ML/ha of water to wet the floor up.
- Seepage and evaporation in the channel you use to move the water. This includes the water required to wet the channel up if it is dry. On-farm channel losses are generally reasonably small, with seasonal channel

losses amounting to less than 2% of total farm water.

- The difference in loss between the existing scenario and the proposed scenario.
- The cost of moving the water.

This [case study](#) illustrates how one grower determined the cost effectiveness of stacking water from 3 storages into 2 storages. In this case the grower had three storages that were partly full. One of these storages contained about 1500 ML and there was sufficient space in the other two storages to empty this storage. The grower had measured the seepage and evaporation loss of his storages using the technology discussed above, so he knew that his seepage loss was 2.9mm/day. He could also apply his dam factor to the average evaporation figures for the next three months that he needed to store the water.

The potential water lost by leaving the 1500 ML in the current storage for 3 months was calculated to be 640 ML. As the other two storages contained water anyway, there was negligible change in storage loss from these storages. Similarly, there were no significant channel losses as the storages were very close together and the channel was already wet.

The cost of pumping the water was estimated at \$10 per ML (10 L of diesel at \$1 per litre) so the total cost was \$15,000. As the amount of water saved was 640 ML, the cost per ML was \$23.40 which was much cheaper than purchasing this water from elsewhere.

Note that a pump test could provide this grower with an improved measure of the true pumping cost.

## Applying water to a field

In some circumstances, it might be worth considering applying water to fields rather than keeping the water in a storage. It might be possible to plant an opportunistic crop which could use this water as soon as possible, although in many circumstances this strategy will be used to apply water to fallow fields. This would be an attractive option when:

- The volume of water in storage is small, and it is likely to be lost before it can be used
- There is no alternative storage in which the water can be put.
- The storage has very high losses and the water will be rapidly lost.

There are still a number of factors that should be considered:

- By applying water to the field you may reduce the ability for the field to capture upcoming rainfall. If it does rain, you may still be able to capture this water as excess runoff, but you will now have to pay to pump it into the storage. This should be considered if the probability of rainfall is high.
- Some amount of soil evaporation is likely. Where water is contained in a deep storage with a small surface area, and the field area over which this water would be applied is large (for example if the soil has low moisture holding capacity or already contains substantial moisture) then the benefit of applying the water to fields should be carefully considered.
- Fallow fields should be managed in accordance with appropriate moisture conservation techniques (such as retaining standing stubble and managing weeds).
- Deep drainage research has found that most water is lost early in the season, when soils are likely to be driest (see WATERpak Chapter 1.5). The potential for losing water applied to fields as deep drainage should be considered.

## Other options

Wind breaks may also be effective at reducing evaporation by altering the wind speed across the water surface. Trees have often been used for this purpose, although the actual extent of evaporation reduction is not well known. Importantly, the roots of any vegetation will seek out water and they can threaten the integrity of the embankment. Even some grasses have been known to penetrate deeply (up to 9 metres) into storage walls in search of moisture. In addition, vegetation in close proximity to an embankment will make routine embankment access or maintenance difficult.

It is therefore recommended that any vegetation is kept at a reasonable distance from storage walls. It is probably best to have trees at least 15 metres from the toe of the wall. More information on vegetation near storages is available in the [Guidelines for Ring Tank Storages](#).

Some have suggested that floating or emergent vegetation within the storage could be used to reduce the water surface area exposed to open evaporation. However any vegetation, either floating on the surface or emergent deep rooted, will actively transpire and therefore water loss will continue to occur. The vegetation will enhance the surface roughness of the water and may actually enhance water vapour transfer rates compared to the smooth surface of open water. Therefore such practices are not recommended.

## Structural Modifications

Storage structural modifications aim to minimise the surface area of water available for evaporation and seepage for a given volume of water stored, thus reducing overall losses. This can be achieved by:

- Splitting a storage into cells. In this case, when the volume of water is low it can be concentrated into a smaller area.
- Raising the height of a storage. In this case, it might be possible to reduce the use of a second storage by concentrating the water into a single, deeper storage. Alternatively, it might be worthwhile moving the wall of an existing storage to decrease the storage footprint but at the same time raise the wall height so the volume of water stored does not change.
- Modifying the storage to remove an area of high seepage.

### Divide a storage into cells

[Dividing a storage into cells](#) allows it to be better managed to reduce evaporation and seepage losses by concentrating water into a smaller surface area whenever possible. Smaller cells will also reduce wind action. This strategy is particularly useful for reducing losses during periods of low water availability, and storages which often contain small proportions of water are most likely to benefit.

The effectiveness of cells at saving water will depend on the storage water holding pattern and the relative size of the cells. For example a storage which is often 70% full but has two equally sized cells will regularly have water in both cells and therefore savings will be low. Determining the optimum cell proportions is important when considering this strategy. Similarly, the savings from storages which only hold water for a small period of time will most likely be low.

Storages that have been divided into cells will require some additional maintenance of the dividing wall, although this should not be a significant burden. The main consideration in operating cells is how the water is managed and transferred between cells. The ability to extract water from either cell will provide management flexibility. Cells should be able to be drained of all water, as any water remaining in a cell will result in evaporation loss. When managing water between cells, the volume of water that may be lost when wetting up a dry cell should be accounted for. This loss may be up to 2.5 ML/ha for a very dry cell.

The [construction standard](#) of the dividing wall needs to be just as high as for the outside embankments. In this case, however, both batters need to be flat to minimise erosion: at least 5:1 and preferably 8:1.

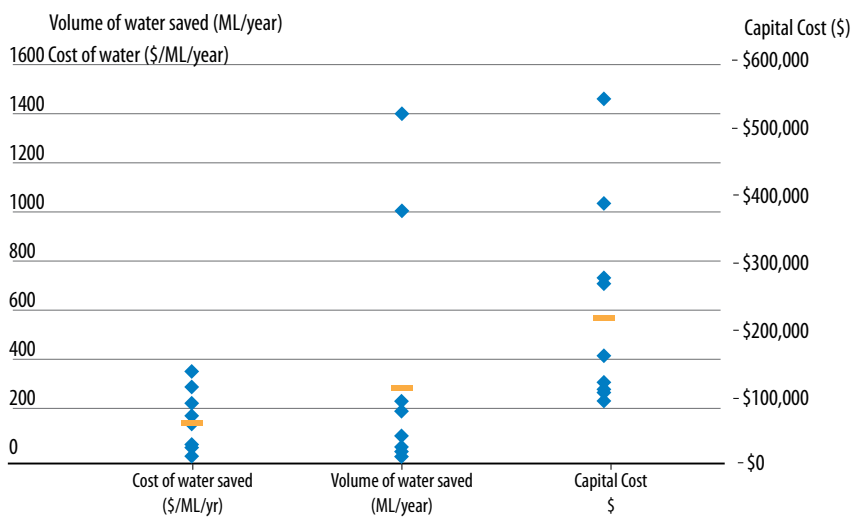
In addition, the core of the dividing wall needs to be carried through to join the core of the existing outside embankment. That is, the inside batter of the original embankment needs to be removed at the proposed junction, leaving the core exposed. The scrapers should remove some of the existing core to provide a sufficiently flat slope to bond with the core of the dividing wall, by watering and rolling. The original batters are then re-established, joining with the new.



A similar procedure is required if a new, external cell is added to a storage, with the core of the new embankment bonded to the old.

The cost effectiveness of cell division strategies will vary depending upon individual circumstances, although [recent evaluation](#) across a number of properties in the Queensland Murray Darling Basin showed that this strategy was cost effective in most cases. As illustrated in Figure 1.6.9, the cost of water saved was generally quite reasonable, with only 3 out of 11 storages having a cost above \$200/ML/year. The lowest cost was around \$15/ML/year with the highest cost \$350/ML/year. The cost of earthworks for cell construction will vary depending upon individual requirements. A cost of \$3/m<sup>3</sup> was typically used for these calculations.

Figure 1.6.9 - Results of cell division strategies on 11 storages. Orange markers indicate the mean of all values.



## Raise wall height

[Raising the height of a storage](#) wall will allow it to hold more water without substantially altering the surface area. Whilst this will provide a better ratio of water loss per ML of water stored, the total volume of loss will still be the same. This strategy is most effective when:

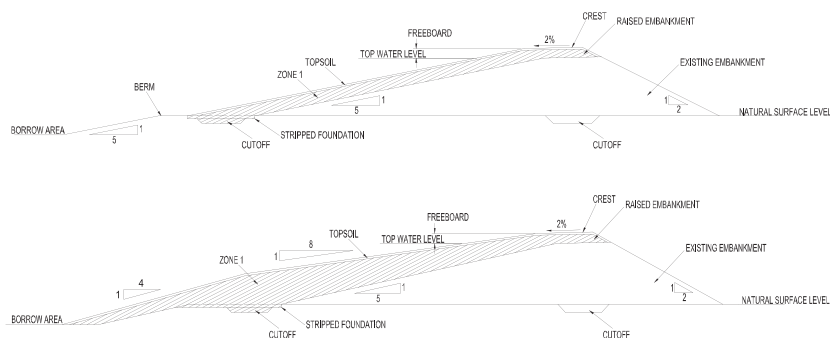
- The total volume of on-farm storage is going to be increased. Increasing the height of a current storage will most likely result in lower losses than building a second storage.
- The walls of one storage are raised so that it can hold water that is currently stored in a second storage. In this case, the losses from the second storage will be saved.
- The wall of a storage is moved to reduce the overall footprint and the height is raised so that it stores the same volume of water.

As with cell division strategies, the water savings will depend on the storage characteristics and the water holding pattern. The finished height of the storage wall can influence the cost of construction and may have regulatory impacts that need to be investigated. There will also be an increase in maintenance costs as the wall area has increased.

[Two possible methods of raising the embankment](#) are shown in Figure 1.6.10. In the first figure, the embankment is raised on the original profile (5:1 inside batter). In the second figure, the embankment is rebuilt with an 8:1 inside batter. The second is preferable but requires more fill, particularly if the existing borrow pit needs to be fully or partially refilled. In both cases a new core and cut-off trench is required, backfilled with compacted moist select clay. Foundations need stripping and topsoil is to be replaced. Whilst it might seem attractive to place the new fill on the outside batter, particularly if the storage is holding water at the time, this option should be avoided.

In raising the embankment, exacting design and construction standards are required for the new works, particularly as the construction standard of the original works may be unknown. These standards are outlined in the [Guidelines for Ring Tank Storages](#).

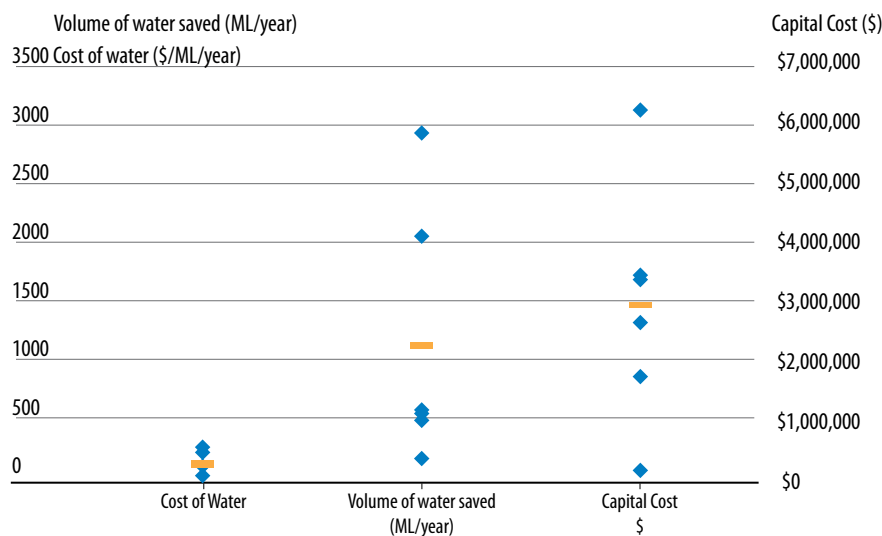
Figure 1.6.10 – Construction methods for raising the embankment of a storage wall. Source: [Guidelines for Ring Tank Storages](#).



The cost effectiveness of raising wall height will vary depending upon individual circumstances. [Recent evaluations](#) for six properties in the Queensland Murray Darling Basin showed that this strategy was cost effective in most cases. These scenarios mostly involved raising the height of one storage so that it could fit the contents of a second storage, which could then be decommissioned. One particular scenario involved moving one wall of an existing storage so that the footprint was reduced whilst simultaneously increasing the wall height so the volume stored remained the same.

As illustrated in Figure 1.6.11, the cost of water saved was generally quite reasonable, with only two out of six storages having a cost above \$200/ML/year. The average cost of water saved was \$169/ML/year, and the cost ranged from \$61/ML/year to \$300/ML/year. The volumes of water saved were often considerable, although the capital cost was also high. The cost of earthworks used in these case studies was typically \$3/m<sup>3</sup> and, where required, the cost of failure impact assessments was usually included. Earthwork costs may increase depending upon the difficulty of work required.

Figure 1.6.11 - Results of wall height strategies on 6 storages. Orange markers indicate the mean of all values.

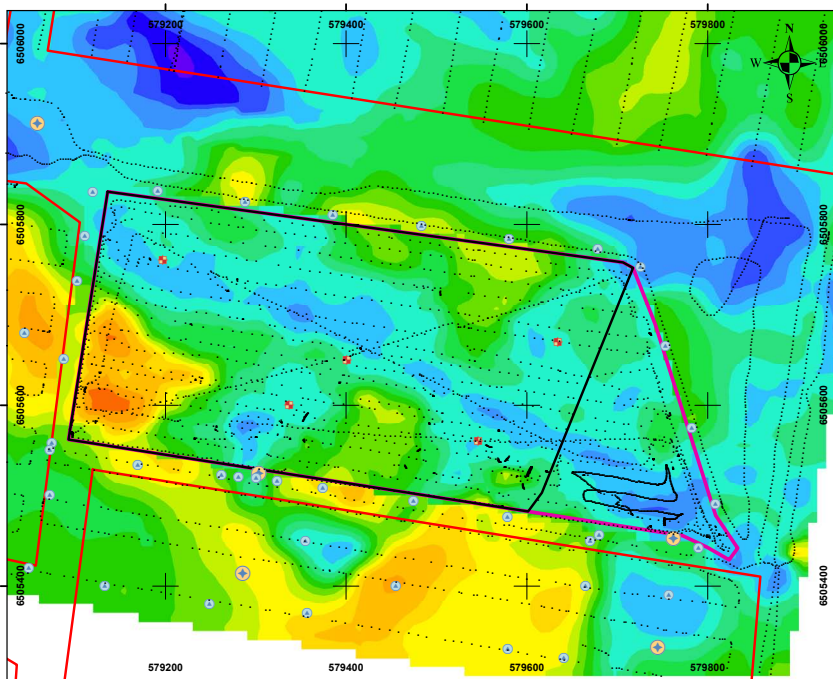


## Modify storage shape

In some cases, modifying the position of a storage wall can be a useful way of excluding an area in which seepage is occurring. As such a modification will most likely reduce the volume of the storage, it is important to be sure that the area which is being excluded is the source of the seepage and that the entire area at fault is being removed. There would be nothing worse than spending money on building a storage wall to find out that the storage still leaks! A case study of a grower who moved a storage wall to exclude an area of high seepage is included in a publication of [Seepage Remediation Case Studies](#).

In this case, the corner of a storage was thought to be leaking and causing most of the seepage loss within the storage. The seepage was also affecting a portion of a nearby field, causing waterlogging. A soil specialist was called in who determined the extent of the area that was causing the problem and a new wall was designed so that the offending area could be removed from the storage.

Figure 1.6.12 – An EM survey was one of the techniques used to diagnose the leaking area of the storage, shown in blue in the bottom right hand corner.



Key factors when selecting these products are the effectiveness of the solution, the capital and operating costs involved, the impact on water quality and dam safety. Uptake of these products in the cotton industry has largely been limited by cost effectiveness.

Those products that are very effective also tend to be high cost whilst those products which are low cost tend to have poor or variable performance. An analysis of the strengths and weaknesses of a range of evaporation solutions is [available online](#). Ongoing research is attempting to make these solutions more cost effective.

## Evaporation

Solutions particularly aimed at reducing evaporation generally revolve around applying some form of barrier or treatment to the water surface. There are a wide range of products available for controlling evaporation, which broadly fall under the following categories:

- Continuous floating covers
- Modular floating covers
- Suspended structures (shadecloth)
- Chemical covers

## Continuous floating covers

[Continuous floating plastic covers](#) act as a physical impermeable barrier that floats on the water surface and can achieve above 90% evaporation savings for full cover of the dam. Many different materials have been trialled in the past including wax, foam and polystyrene, but polyethylene plastic has proved to be the most satisfactory and durable material for covers of this type.

Figure 1.6.13 shows a newly installed floating cover on a 4 hectare dam near St. George. This particular cover is the Evap-Cap product which consists of a multi-layered, polyethylene membrane containing buoyancy cells, similar to bubble wrap or existing swimming pool cover products, although the material is much tougher to resist degradation from sunlight. Holes in the plastic allow rainfall to infiltrate below the cover. The top of the material is white to reflect heat whilst the underside is black to restrict light transmission, which reduces algal growth. Other products include plastic films with no inbuilt buoyancy which require separate flotation and securing systems.

Figure 1.6.13 – A floating cover installed on a 4 hectare dam near St George, Qld.



Water quality changes can include reduced dissolved oxygen, and a change in water temperature. Complete covering of a storage can impact on bird and fish life.

Significant difficulties can be encountered with installation on large storages above 5 hectares; therefore this is generally the largest size storage for which these products are suitable as a single cover. However the product can be deployed in sections on large dams and in some cases these covers can be deployed as a series of large rafts covering up to 1ha. The installation method and the procedure used to attach the cover to the embankment are important considerations, as is the structural integrity of the product under windy conditions and fluctuating water levels.

Tests have demonstrated that when well managed, these covers are over 95% effective in reducing evaporation from open storages. However, most of these products have a high capital cost and replacement life varies (typically between 10 and 20 years). The cost effectiveness of these systems suggests that they are likely to be more suited to storages which water in them all year round and/or where the productive return on water use is sufficiently high.

Table 1.6.2 - Advantages and disadvantages of continuous floating covers (Source: DERM (2010), Appraisal to identify and detail technology for improving water use efficiency in irrigation in the Queensland Murray Darling Basin)

Advantages	Disadvantages
Highest average evaporation reduction of evaporation solutions	Dust build-up and the growth of weeds on top of the cover
Lowest variability in performance	High capital and maintenance costs
Easy to determine the likely water saving with a high degree of confidence	Disruption to surface wildlife and change in the environment and water quality beneath the cover
Relatively easy to install	High winds may cause damage and removal of cover
Potentially reduces algal growth	Use of cover limited to storages <5 ha
Potentially improves water quality and reduces salinity.	Capital cost is providing no return during dry periods
Low level of expertise required	
Long lasting (10 – 20 years)	

## Modular floating covers

[Modular floating covers](#) are another type of physical cover which provides an impermeable barrier between the water surface and each individual module. Individual modules come in a range of sizes up to an area of around 3 m<sup>2</sup>. Whilst they do not have the structural challenges of a continuous cover, and installation is generally quite easy, they often cover a slightly smaller portion of the total storage surface due to the small gaps between each module. The evaporation reduction performance will depend on how tightly the modules pack together and will generally be slightly lower than for a continuous plastic floating cover, although modular systems still provide savings of up to 90% when applied to the entire surface.

Modular floating covers can also be deployed to cover only a portion of the storage, for example a borrow pit or low portion that always contains water. Modules can be free floating or connected together to form a larger raft. The actual area covered will depend on the number, shape and size of the module and the storage characteristics. Their flexibility and ease of installation (especially when allowed to float freely) is well suited to deployment on large storages. However, stability under high winds is critical and the impact of high flow periods and wash through spillways needs consideration.

Modules are typically made from a plastic material and usually have a reasonably high capital cost (in excess of \$20/m<sup>2</sup>). Repair and replacement of modules is reasonably simple. Existing products include Aqua Armour, AquaCap and Raftex. The cost per unit and life of the product will be important in determining the economic viability.

Possible water quality impacts may be similar continuous floating covers, depending on the relative area covered.

Table 1.6.3 - Advantages and disadvantages of modular floating covers (Source: DERM (2010), Appraisal to identify and detail technology for improving water use efficiency in irrigation in the Queensland Murray Darling Basin)

Advantages	Disadvantages
Individual modules can be repaired or replaced	High variability in performance between commercial covers available
Virtually maintenance free	High capital cost
Progressive purchase enables initial cost to be spread out over longer period of time	Disruption to surface wildlife
Lightweight, quick and easy to install	Difficult to cover 100% of storage
Possibly improved water quality through reduced algae	Modular cover may not refloat if left in a muddy storage
Low level of expertise required easy to install and maintain by irrigator	High winds may cause movement and loss of covers, especially on dry storages

## Suspended structures

**Suspended structures** (also [see here](#)) usually consist of shadecloth which is suspended above the water surface using a cable structure. The shadecloth reduces solar radiation and wind speed and increases humidity between the structure and the water surface, which all combine to reduce evaporation. The shade cloth can come in a range of UV ratings which describe the amount of UV blocked by the shade cloth.

In general shade structures are not as effective in reducing evaporation as floating covers, with evaporation savings of 70% to 80% demonstrated in trials. However shade structures are a proven technology used for many years in fruit production and there is reduced impact on water quality and aquatic life, although algae growth is typically reduced owing to less light penetration.

Most of these products have high capital and low ongoing/running costs but all have a limited lifetime. The cable system typically has a lifespan of over 30 years with the shadecloth most likely requiring replacement once during this period.

They are more appropriate to small storages given the need to suspend the shade cloth above the water, with the maximum suitable storage size being approximately five hectares. The limiting factor is the ability to construct the cable structure.

Hail shoots or valves can be installed into the cloth to reduce the potential for damage. As shadecloth is porous, it allows rainfall to penetrate readily. This means that wind blown soil does not collect on the surface (it either blows off or falls through) and the growth of weeds or algae on the cover surface is therefore unlikely. Furthermore, dam management has no effect on the shadecloth, as it is not in contact with the water. Therefore the storage can be drained and filled without consideration or monitoring of the cover performance.

Table 1.6.4 - Advantages and disadvantages of suspended shade structures (Source: DERM (2010), Appraisal to identify and detail technology for improving water use efficiency in irrigation in the Queensland Murray Darling Basin)

Advantages	Disadvantages
High evaporation reduction	High capital outlay and maintenance costs
Reduces wave action	Limited applicability
Enables entry of wildlife onto storage	Use of cover limited to storages with a surface span less than 120m (typically <5ha)
Allows access to the storage for maintenance operations	Satisfactory anchoring in some poor soils may be difficult
Possibly improved water quality through reduced algae	Specialist skills and significant engineering design required for footings and high tensile cables
Permeability of cover allows direct rain entry and prevents debris build up	
Existing expertise for installation	

## Chemical covers

Chemicals which can be applied to water storages to reduce evaporation have potential as low cost methods for reducing evaporation losses and are likely to be particularly well suited to larger storages. However, chemical methods are generally not as effective at reducing evaporation as physical controls. Water savings have been shown to be highly variable, from less than 5% to up to 40% and are strongly impacted by the chemical type, weather conditions, water quality and application method.

Existing [chemical products](#) (also [see here](#)) are typically either monolayers or chemical films. Monolayers (for example WaterSavr) form a one molecule thick film (monolayer) on the water surface. Existing monolayers are typically long chain cetyl/stearyl alcohols. Other chemicals which form a film on the water surface (such as Aquatain, a silicone based product) are not true monolayers but may also reduce evaporation.

The main limitation with existing products is their variable performance. New generation monolayer products which hope to provide more predictable performance are currently being developed. The advantages of chemical products are comparatively low upfront capital costs and the fact that the product only need be applied when required. Therefore when there is no water in storage the amount of inactive capital is small.

Monolayer molecules are designed to biodegrade readily to minimise adverse environmental impacts. Therefore frequent, repeat application is necessary (between one and ten days). Recent research has suggested that monolayer products do not adversely affect water quality, although water quality can have a major impact on the durability (lifespan) of the monolayer. Surface film products that are not monolayers (e.g. Aquatain) are likely to have very different environmental performance characteristics which do not appear to have been widely researched.

Application of the monolayer product on small storages may simply be achieved by hand from the bank as the chemical has some self-spreading ability. For larger storages, an intelligent application system is under

development which can determine the optimum application strategy depending upon current weather conditions and the presence of product on the surface. A distributed network of applicators can then apply product where required to achieve the most cost effective application strategy. Such a system may also be able to select the best monolayer product to match the water quality characteristics and climate of your water storage.

With the current price of water, chemical covers could provide an economically viable option for large agricultural water storages above ten hectares in size, especially if their performance can be improved. They are particularly suited as a less capital intensive investment option for owners of storages with less reliable water supply. Whilst the chemicals typically only last for between one and ten days, application equipment is likely to last for 20 years.

Table 1.6.5 - Advantages and disadvantages of chemical covers (Source: DERM (2010), Appraisal to identify and detail technology for improving water use efficiency in irrigation in the Queensland Murray Darling Basin)

Advantages	Disadvantages
Low initial setup cost	Low evaporative reduction
Lower risk investment for ephemeral storages	Highly variable performance and uncertainty of water savings
Suitable for storages in dry periods	Monitoring of the presence of cover is difficult
Flexibility and ease in application of cover	Not suitable in windy locations
Can be applied only when needed	Possible environmental and water quality concerns
Biodegradable product should limit potential environmental impact	Biodegradable product means longevity is affected
Can potentially be applied by aircraft	
Suitable for large storages	
Can use automatic applications	

## Seepage

### Identifying seepage problems

If you have identified a seepage problem by measuring your seepage and evaporation losses, the next step is to identify where the seepage is occurring. [Case studies](#) of growers who have identified and addressed seepage problems suggest that seepage usually occurs through discrete pathways such as patches of sand or gravel or prior stream beds (paleochannels). In some cases identification of the problem area can be achieved visually when the storage is empty as there will be evidence of tunnelling or areas displaying soil characteristics or moisture levels inconsistent with the surrounding vicinity.

However, most problems are more difficult to identify, and a number of other methods need to be employed.

### Soil Imaging

Non-invasive soil imaging techniques such as EM (electromagnetic) surveys (see WATERpak Chapter 2.6) are a cost effective way of looking at the entire storage area. Most of these techniques measure the electrical conductivity (EC) of the material within the sample volume. Electrical conductivity in soil is principally affected by the level of salinity, moisture content and clay content. Therefore, when properly ground truthed to take account of variations in moisture and salinity, these techniques can provide an indication of soil type differences and can be useful aids in identifying areas in which seepage might occur.

EM surveys are the most commonly utilised technique for imaging in agricultural soils and are most frequently conducted using EM31 and EM38 equipment. In typical use, this equipment provides an interpretation of the

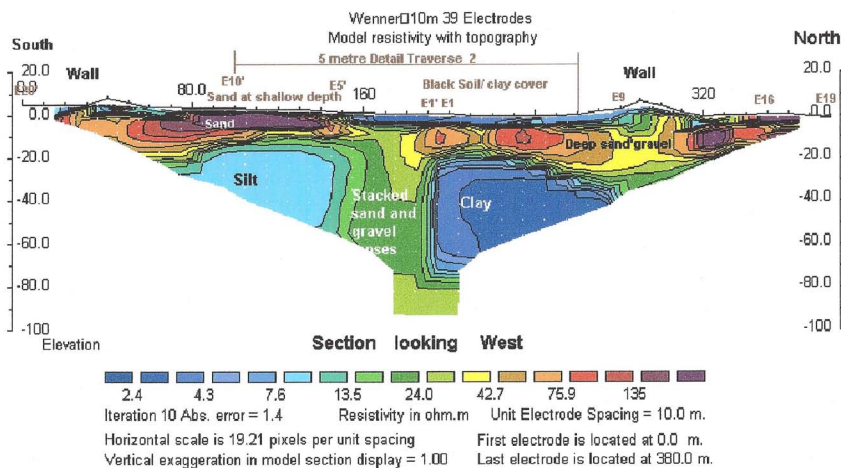
average bulk soil parameters which provides adequate data for most precision agriculture applications. The commonly used EM equipment provides information to depths of around 1 metre (EM38) and 6 metres (EM31), although a range of alternative EM meters exist with various characteristics and operating depths. Figure 1.6.12 showed an example of a storage EM survey.

More sophisticated techniques and equipment are capable of providing additional information such as multi depth imaging. In this case, the specific characteristics of soil at different depths can be identified, rather than an average of the characteristics over the total depth of measurement. Such techniques might be particularly relevant for identifying storage seepage issues, where specific soil artefacts have been unable to be identified through EM surveys. In particular, the presence of seepage pathways (such as sandy paleochannels) which are otherwise surrounded by clay material can sometimes be difficult to identify using EM surveys alone.

Geoelectric devices (often referred to as DC Resistivity techniques) have been used within the cotton industry more recently, although their use is still confined to a small number of cases at this stage. These devices are capable of providing information on soil at specific depths within the soil profile, and operate across a wide range of depths from less than 2 metres to greater than 40 metres. Some devices can also be adjusted so that the total depth of measurement can be varied. These devices require good electrical contact with the ground or water and have been typically employed in research projects with electrodes hammered into the ground to provide a single

transect of information. However it is also possible to tow some devices, which is particularly practical on water surfaces and is therefore particularly relevant for identifying soil characteristics in storages. Figure 1.6.14 provides an example of the type of information that may be produced by such devices.

Figure 1.6.14 – Example resistivity image from an on-farm storage.



Some existing EM surveys have been conducted poorly, although the quality of surveys in general has increased considerably over time as operators have greater experience with the equipment and techniques. Good operators will take into account local conditions that are likely to influence survey results, such as the presence of metal objects. As discussed by David Allen (see [Geophysics for the Irrigation Industry](#)):

*Most EC measuring devices are very strongly affected by metallic objects in their proximity. Shape and grounding of such objects may be very significant. For instance, an ungrounded fence, around a rectangular paddock, with a closed gate may not affect geoelectric devices but may cause problems for electromagnetic devices. Simply by opening the gate, the circuit through the fence may be broken resulting in negligible effect on electromagnetic devices. Similarly, a buried copper pipe may cause problems for a geoelectric device but have less effect on an electromagnetic device.*

In summary:

- Electromagnetic (EM) surveys can provide cost effective mapping of storages and can often identify areas of soil in which seepage is occurring
- EM surveys are not foolproof and may not show specific soil issues in all circumstances
- Alternative techniques such as resistivity imaging can provide additional information including multi-depth analysis of soil characteristics
- Soil imaging complements, but does not substitute, manual investigation. Soil imaging will often need to be ground truthed with sufficient manually collected data and can be used to define specific areas of interest for more detailed manual investigation.

## Clay lining

Perhaps the most commonly employed technique to remedy seepage loss is clay lining. Clay lining is useful where there is sufficient suitable clay available near the storage. In nearly all cases, the clay being applied will need to be compacted in order to provide sufficient impermeability. Earthworks can be expensive to apply and it is important to ensure that the works will reduce seepage sufficiently to ensure they are cost effective.

For very small areas where the total cost is reasonably low, the best approach may be to assume that maximum compaction is required. The information below provides some advice on how to apply compaction appropriately.

For larger areas, it will pay to get professional advice from an engineer or soil expert. This advice will tell you:

- Whether the available soil will achieve satisfactory seepage reduction
- The level of compaction required
- The moisture content at which the compaction should be applied
- How the required compaction should be applied

## Clay liner design

This section will focus specifically on engineered clay liners, which consist of a layer of compacted clay, typically around 300mm to 1000mm thick. Liner thickness will typically increase with the depth of water to be stored. Correctly designed and constructed clay liners can be very effective at reducing seepage, and although more care is required in their construction, they offer the potential of better performance and may require less earth than ad-hoc remedies. Creating clay liners which successfully alleviate seepage problems requires:

- the correct soil type;
- correct construction techniques, including appropriate compaction at the correct moisture content; and,
- maintenance of the liner to ensure effectiveness over time.

Clay liners are widely used in civil engineering projects which require long term restriction of seepage at extremely low levels. For example clay liners are frequently used to line and cover landfill to prevent contaminated water from escaping. When properly designed, constructed and maintained, clay liners can be extremely effective. However if any of these elements is undertaken poorly, the clay liner may be an ineffective and costly white elephant.

The ideal soils for clay liners should contain 12% to 40% clay and be well graded (universal soil classification CI, SC or GC). Heavy clays (universal soil classification = CH) which are common in many cotton areas are prone to cracking when dry which reduces the effectiveness of the compaction. However they can be used if protected by a layer of well graded soil to keep them moist (see below). Where the hydraulic

conductivity is higher, or insufficient compaction is applied, the thickness of the liner will need to be greater.

The amount of compaction that can be achieved is highly dependent on moisture content. In vertisols, soil strength (and hence compressibility) can vary by two orders of magnitude over the range of moisture contents (for a given density) commonly experienced in agricultural operations (Raper and Kirby, 2006). A standardised laboratory test called the Proctor Test provides an indication of the maximum dry density (MDD) that can be obtained for a given compactive effort and the optimum moisture content (OMC) at which this can be achieved.

Figure 1.6.15 provides an indication of the difference in maximum dry density that can be obtained for a number of Darling Downs soils at different moisture contents. For each soil, it is possible to see that when the soil is too dry, the soil strength prevents the maximum dry density from being achieved. When the soil is too wet, the water takes up too much space in the soil voids and prevents further compression. The maximum dry density and corresponding optimum moisture content for each of these soils is included in Table 1.6.6. The range of optimum moisture contents should be noted and is typical of the range that would be expected within most cotton growing regions.

It should also be noted that the maximum dry density calculated in this manner is related to the testing procedure (in this case standard proctor test). If greater compactive force were applied, a higher MDD would be achievable at a lower OMC. Therefore, it is possible for the field density after compaction to be greater than the MDD determined from this test. The proctor test is widely adopted as a suitable test for determining the amount of compaction required for construction of clay liners.

Figure 1.6.15 - Standard compaction for various darling downs soils (source: FSA Consulting, 2001, [Farm Dams for the Sugar Industry](#))

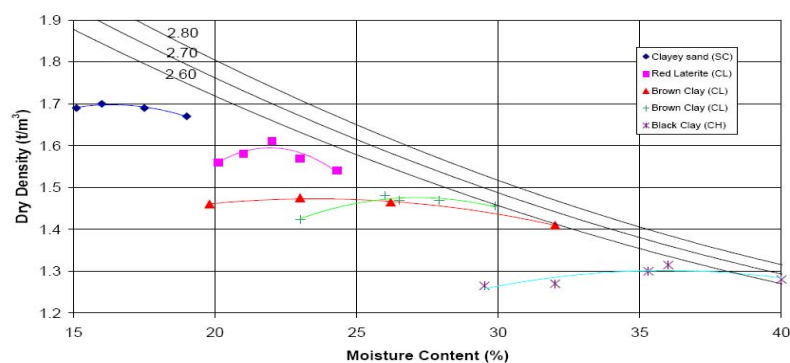


Table 1.6.6 - Optimum moisture content (OMC) and maximum dry density (MDD) for various Darling Downs soils (source: FSA Consulting, 2001, [Farm Dams for the Sugar Industry](#))

Soil Type	Optimum Moisture Content on a dry basis (%)	Maximum Dry Density (t/m <sup>3</sup> )
Clayey Sand (SC)	16.0	1.70
Red Laterite (CL)	22.0	1.61
Brown Clay (CL)	23.0	1.48
Brown Clay (CL)	26.0	1.47
Black Clay (CH)	35.5	1.30

For practical purposes in the field, it is possible to estimate the optimum moisture content by rolling the soil between the hands into a thread four millimetres in diameter (the thickness of a pencil). At the optimum moisture content, this thread will just begin to crumble at this diameter on further rolling.

### Applying compaction

There are a number of misconceptions regarding compaction of clay liners. The biggest misconception is the belief that tractors and bulldozers provide significant levels of compaction. This is not true. Table 1.6.7 provides a guide to the average and peak compactive force applied by different types of equipment.

Table 1.6.7 - Average and likely peak ground pressure of a variety of equipment.

Equipment	Average Pressure (kPa)	Possible Peak Pressure (kPa)	Source (average pressure figures)
Bulldozer (D7)	60	240	Ring Tank guidelines
Bulldozer (D11R 710mm track)	160	640	Caterpillar Performance Handbook
Tractor (equivalent to 12 ply tyre @ 150kPa)	180	360	Farm Dams in the Sugar Industry
Tractor (120kW)	250	500	van den Akker and Soane (2005)
Scraper (not specified)	300	600	Farm Dams in the Sugar Industry
Scraper (62 tonnes)	1530	3060	Ring Tank Guidelines
Sheepsfoot Roller	1750		Farm Dams in the Sugar Industry
Sheepsfoot Roller (16 tonnes)	5000		Ring Tank Guidelines
Sheepsfoot Roller	~8000		Pfost et al. (1997) – 40 times greater than rubber tyres.

Most available information provides data on average ground pressure, which is the weight of the machine divided by the total area in contact with the ground. There has been some speculation that this data is misleading, particularly for tracked vehicles which may apply uneven pressure due to the presence of grousers and the number and location of bogies. Recent research has shown that in many cases the peak pressure under a track can be 3 to 5 times higher than the average pressure and 2 times higher for tyred vehicles (Lyasko, 2010). This information has been incorporated into the table above to provide an estimate of the possible peak pressures for each type of machine.

Ground pressure data for bulldozers is usually supplied by manufacturers as they are specifically designed to have a low ground-bearing pressure to improve traction and flotation in soft conditions, thus preventing the machine from sinking. The average ground pressure, even for very large bulldozers such as the Cat D11, is still less than that for tractors, which are operated with low tyre pressures to reduce compaction in fields. Even if the peak pressure is 4 times the average ground pressure, the compaction provided by a bulldozer is at most similar to that provided by a scraper and significantly lower than that provided by a sheepsfoot roller. Note that bulldozers are specifically used to reinstate topsoil to productive condition in mine site reclamation programs because of their ability to minimise compaction.

For storage construction, large scrapers (Cat 631 or larger) are sometimes considered acceptable to provide sufficient compaction when loaded. It should be noted that in all other fields of construction, scrapers are not considered for their compactive effort and thus information regarding their ground pressure is extremely hard to come by.

Sheepsfoot rollers are specifically designed to provide compaction and are ideally suited to compacting clay soils. In addition, they also provide a method of ensuring that each layer of soil (lift) is well bonded to the previous layer. Suitable rollers would typically have an outside diameter not less than one metre nor be more than two metres long. The length of each tamping foot should be at least 175 millimetres from the outside surface of the drum. When fully ballasted, the roller should not weigh less than three tonnes per metre length of drum.

The recommended procedure for providing compaction is as follows:

1. Ensure that all water has been drained from the area of the storage where work is required. Remove any vegetation, sand or silt to expose a firm foundation on which to place the clay lining.
2. Determine the moisture content of the clay to be used for lining. Moisture content can be estimated using the field technique previously described or through soil sampling. If the soil moisture content is less than specified, add water to the soil and mix thoroughly before compacting. Be aware that adding water and mixing soil can significantly increase the cost of earthworks. If the soil moisture content of the material is higher than specified, the material must not be used until the moisture is uniformly lowered to within the specified range, by light ripping, disc ploughing or other methods that assist evaporation and drying.
3. When the moisture content is optimum, place the material in layers, spread evenly and no thicker than 150 millimetres. Each layer should be compacted with a sheepsfoot roller until the dry density exceeds 95 per cent of the maximum dry density as described in [AS1289.5.1.1-2003](#) (or see Table 1.6.6). Normally, six to eight passes of the sheepsfoot roller will be required to achieve the specified compaction. In practice, the compactor should be 'walking on its toes' by this time but still leaving indentations (that is, not a smooth surface). Daniel (1993) provides the following recommendations:

*Heavy, footed compactors with large feet that fully penetrate a loose lift of soil are ideal. Recommended specifications include:*

- Minimum weight: 18000 kg
- Minimum foot length: 180-200 mm
- Minimum number of passes: 5

*More passes may sometimes be needed. A pass is defined as one pass of the compactor, not just an axle, over a given area, and the recommended minimum of five passes is for a vehicle with front and rear drums. In the US, the Caterpillar 815B and 825C are examples of equipment in widespread use that have led to satisfactory results in most cases.*

### Maintaining Compaction

Compacting a surface layer which is subsequently allowed to dry out and crack is not likely to be cost effective, as the effectiveness of the compacted layer will be quickly diminished once cracking occurs. In these situations, a layer of covering material will be required to prevent the compacted layer from drying out. The publication [Farm Dams for the Sugar Industry](#) suggests that a 100mm layer of compacted, well graded material can be placed over the top of the clay liner to prevent drying. However for storages which may be dry for long periods of time and therefore may tend to crack significantly, a thicker layer (>300 mm) might be appropriate. It may not be necessary to compact the full layer where thicker layers are employed.

When storages do dry out, it is important to conserve soil moisture to prevent cracking if possible. Regular weed control is very important. Existing storage guidelines recommend against growing crops in any storage, and this is especially so when time and money has been invested in a clay liner. Therefore crops should never be grown in a storage when a clay liner has been applied. Once cracking has occurred, the level of compaction may be reduced upon subsequent swelling, so investment in crack prevention will help to preserve the capital cost of the clay liner construction.



## Impact Rolling

Impact rolling is a compaction technique utilising massive non-circular modules. As the module travels across the soil, the non-circular shape causes flat sections of the module to be slammed down onto the soil surface. Self propelled and trailed equipment with drums of between 3 and 5 sides have been used, although the most commonly used technique in cotton growing regions involves a 4 sided trailed drum with a mass of 8 or 12 tonnes (Figure 1.6.16).

Figure 1.6.16 – An example of an impact roller at work (photo courtesy of Broons)



This equipment is seen as attractive for use on reasonably large areas as it has a working speed of around 9 to 12 km/hr and is often used without significant (or any) associated earthworks. The impact roller aims to provide deep compaction (in excess of 300mm) which suggests that it is not necessary to apply compaction to the soil in multiple layers (as in the case for sheepfoot rollers).

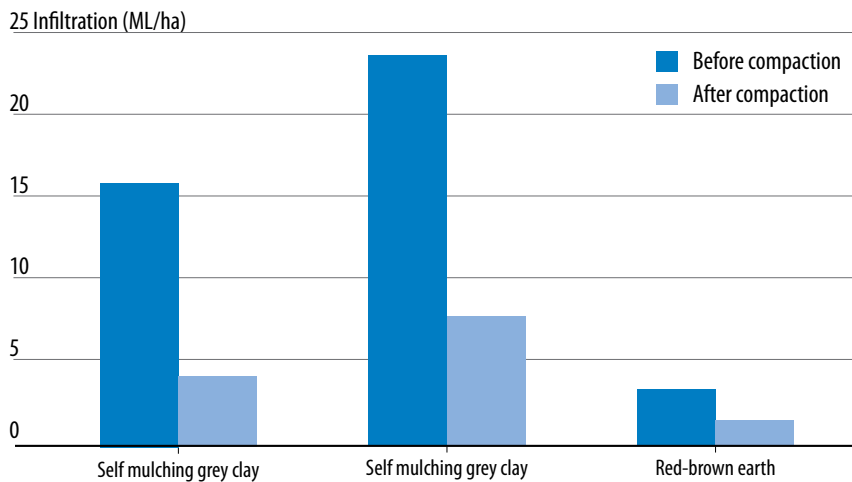
The bearing pressure of an impact roller is not uniform across the area of impact. The corner, for example will provide a static load over a reasonably small area whereas the impact site will provide a dynamic load over a larger area. The dynamic load is still only applied by a portion of the “face” of the roller, not the entire surface. Load cell testing by the manufacturer has suggested that the peak bearing pressure is around 2200kPa. This peak pressure is likely to be applied by an area of less than 20% of the drum surface; however the area of influence will increase with depth in the soil. Multiple passes should provide some uniformity to the compactive effort within the soil.

There is little definitive data regarding the recommended soil moisture for achieving maximum compaction, with various recommended moisture content ranges including: 2% below OMC; 2.5% to 4% below OMC; and up to 7.5% above OMC. Given the impact roller aims to exert compaction

at reasonable depths, it would be important to ensure that the moisture content throughout the soil profile is within reasonable limits. Where varying soil moisture exists, it would be reasonable to accept lower soil moisture in the surface layers (0 – 25 cm) in preference to excessively high moisture in lower layers (50 – 75 cm). Impact rollers are not designed to provide compaction in surface layers where the impact and shearing forces can actually reduce compaction.

Research on the use of impact rollers to [seal soil in rice fields in southern NSW](#) showed that water infiltration could be significantly reduced if the soil moisture content was greater than about 20% (for these particular soils). The impact roller had virtually no effect when the soil was dry and hard. Infiltration was reduced by 40 to 60 per cent on soils with relatively low initial infiltration rates and was reduced by 70 to 80 per cent on “very leaky” soils (Figure 1.6.17).

Figure 1.6.17 – The effect of impact roller compaction on infiltration in selected soils of Southern NSW (adapted from [Reducing recharge from rice fields](#))



In cotton growing soils, Auzins and Southcott (1999) measured various soil parameters during the use of an 8 tonne impact roller on irrigation channel banks at Lake Tandou in Western NSW. This work showed that:

- Hydraulic conductivity under the middle of the impact roller was reduced to an unmeasurably low value at 0.5 and 0.75 metres below the soil surface following 15 passes of the roller. However the soil structure within the top 0.5m profile was periodically shattered by the roller, thus temporarily increasing the conductivity (for example conductivity at a depth of 0.5 metres initially decreased after 5 passes, then increased after 10 passes before reducing to undetectable levels after 15 passes). Similar patterns of increased hydraulic conductivity were detected after ten passes in all trials.
- Hydraulic conductivity at the edge of the embankment (outside the roller footprint) actually increased for one trial. It was concluded that the roller encouraged cracks to develop in this area and was attributed to high soil moisture content. This phenomenon may not be a concern on storages where multiple adjacent roller passes occur.
- Cone penetrometer readings suggested that penetration resistance generally increased below around 0.25m in depth. However penetration resistance decreased in the top 100mm, which is consistent with previous research which suggests that the impact and shearing in this zone causes soil loosening.

Avalle (2004) summarises data from three case studies as presented in Tables 1.6.8, 1.6.9 and 1.6.10. It should be noted that these tests may not be scientifically rigorous, and there is no evidence of replication in the trial design.

Table 1.6.8 - Effect of storage floor impact rolling on infiltration using large scale double ring infiltrometer, Clyde Agriculture, Bourke.

Number of passes of impact roller	0	6	12
Infiltration rate (mm/day)	0.30	0.21	0.05

Table 1.6.9 - Effect of channel bank impact rolling on soil density as a percentage of standard compaction, Murrumbidgee Irrigation, NSW.

Percent Compaction	Before Rolling	After Rolling
Surface	91.0%	-
0.5 metres	-	97.5%
1.6 metres	99.0%	99.5%

Table 1.6.10 - Effect of channel bank impact rolling on infiltration at a depth of 100mm using a small scale double ring infiltrometer, Marthaguy Irrigation, NSW.

Number of passes of impact roller	0	5
Infiltration rate (mm/day)	210	No infiltration measurable after 1 hour

Auzins and Southcott (1999) suggest that routine testing should occur during all impact rolling operations. The testing they suggest includes:

- Determine the optimum moisture content (OMC) for the soil at the compaction site.
- Determine the initial soil moisture content at a representative depth (e.g. half the expected depth of compaction) and ensure it is within reasonable limits of the OMC.
- Undertake initial penetration resistance (e.g. cone penetrometers) or in-situ density tests.
- Undertake penetration resistance or in-situ density tests following compaction to provide a quick indication of the effectiveness of the impact roller.

Further case studies of impact roller use are included in the [Seepage Remediation Case Studies](#) publication.



## Bentonite

**Bentonite** is a naturally occurring non-toxic clay which is commercially mined and has excellent swelling characteristics. When wet, it expands to 10 to 12 times its dry size. When applied in sufficient volumes, bentonite can form a layer with very low permeability. Bentonite can be applied in three different ways; blanket, mixed blanket and broadcast (sprinkle method). The blanket and mixed blanket techniques are generally more effective, capable of achieving seepage reduction of 65% to 95%. The broadcast method is more likely to achieve seepage reduction of 30% to 50%.

Note that the volumes of bentonite recommended below are often in the order of 100 to 150 tonnes per hectare. Some examples of bentonite application which have been unsuccessful (for example, see [Seepage Remediation Case Studies](#) booklet) have occurred at lower rates (30 t/ha or less). The recommended application rate should be understood before committing to, or ruling out, bentonite as an option. Where low application rates are pursued to minimise costs, particularly over large areas, there is significant potential that the application not be sufficient to achieve success. However, when applied correctly, bentonite can be very effective, and is widely used in civil engineering works to prevent water movement.

### Blanket/pure blanket

The blanket application method involves placing a layer of pure bentonite on the bottom of the storage. This method usually involves removing at least 150 mm of soil from the area to be treated. A layer of bentonite is spread evenly over the area at a rate of approximately 10 – 15 kg/m<sup>2</sup> (100 to 150 t/ha). The blanket may be compacted to ensure an even thickness and is then covered with the soil that has been removed to protect the bentonite layer from cracking, animals and vegetation.

It is likely that storages in highly cracking soils may need a covering layer of greater than 150 mm thickness to protect the bentonite layer from significant disturbance during cracking. This would be especially relevant for storages which hold water irregularly and are known to dry out considerably. In these cases, a covering layer of over 300 mm might be more appropriate.

### Mixed blanket

The mixed blanket method involves incorporating bentonite into a layer of soil. For most soils, around 7 – 15 kg/m<sup>2</sup> (70 to 150 t/ha) of bentonite is required for incorporation into a 150 mm thick soil layer. For best results, the soil should be just moist enough to be worked easily. The soil should be harrowed or disked to approximately 150 mm before the required rate of bentonite is broadcast over the soil. The bentonite and soil layer should be mixed to achieve a uniform layer. The mixed blanket method may be less effective than the blanket method if there is uneven mixing of the bentonite. The incorporation operation should ensure that there are not strips or spots where the bentonite concentration is too low. Once the layer is uniformly mixed it should be compacted with a roller.

Although it is not mandatory, the performance of the mixed blanket method may also be improved by placing a protective soil covering over the bentonite layer. This would be most appropriate for storages in cracking soils that have frequent wet and dry cycles where the bentonite layer and the surrounding soil might be expected to mix over time due to cracking. A protective layer would aim to keep the bentonite layer moist and prevent significant frequent cracking.

### Broadcast (sprinkle method)

Broadcast application allows bentonite to be applied to a storage which contains water by sprinkling the bentonite over the water surface. The recommended rate is usually around 10 kg/m<sup>2</sup> (100 t/ha). The bentonite settles to the bottom where it can swell and help to seal the storage floor. This method is not likely to be as successful as the blanket application methods (30 – 50% reduction), and there is little information regarding the longevity of this solution in storages which are regularly emptied.

## Effectiveness

The effectiveness of bentonite application has been well researched in the civil engineering field as this product is often used for civil engineering projects. However data from rigorous testing of bentonite in the cotton industry is difficult to find. Trials in Emerald in 2001/02 (see case study at the end of this chapter) showed that the effectiveness of bentonite was possibly compromised when soil cracking occurred.

Bentonite application was also trialled on a number of Darling Downs soils using in-situ ring infiltrometers and laboratory tests in 2005/06. The [infield tests](#) involved installing ring infiltrometers into the base of 4 different storages and applying bentonite granules to the ponded water (broadcast method) at a rate of 10 kg/m<sup>2</sup>. The results showed a reduction in seepage of between 30% and 50% as indicated in Table 1.6.11. It should be noted that the application was not replicated and the results may not be scientifically rigorous.

Table 1.6.11 – The effect of bentonite application on four Darling Downs storages. Source: Hare (2006).

	Storage 1	Storage 2	Storage 3	Storage 4
Seepage before mm/day	3.29	6.02	58.77	33.37
Seepage after mm/day	2.3	3.17	31.83	19.73
Reduction %	29.9%	47.3%	45.8%	40.9%

Laboratory testing of a bentonite and soil mixture was also conducted on three Darling Downs soils (Campin, 2007). The soil mixture tested was equivalent to a mixed blanket application of 5 kg/m<sup>2</sup> of Bentonite in a 300mm thick layer. The reduction in hydraulic conductivity generally ranged from around 5% to around 60% with an average of 30%. However it should be noted that the ratio of bentonite to soil in this test (5 kg/m<sup>2</sup> in a 300mm soil layer) is lower than the recommended rates for mixed blanket application as outlined above (7 – 15 kg/m<sup>2</sup> in a 150 mm soil layer).

## Polyacrylamide (PAM)

Polyacrylamide (PAM) is a chemical belonging to a class of synthetic polymers with long-chain chemical structure and high molecular weight. During production, the length of the polymer can be varied, causing a significant change in its chemical behaviour and functional attributes and making it suitable for a wide range of industrial applications. PAM is believed to have low environmental and public health impacts, requiring little or no regulations over its widespread use.

[PAM has been used widely in irrigation](#), where a small quantity (1 to 2 kg/ha) of food grade quality anionic PAM is typically introduced into the irrigation water to reduce erosion. Erosion reduction is typically due to flocculation that increases settling of sediment within the furrow. PAM has also been found to increase infiltration in medium and fine textured soils (loam to clay) with low organic matter which may be prone to dispersion. In these cases,

PAM has acted to stabilise the soil structure, thus reducing surface soil sealing and improving infiltration.

However it has been noted that infiltration may decrease under high PAM concentrations. In Australia this has been noted in laboratory experiments using sandy soil columns and PAM treated water. Within the cotton industry, some growers inadvertently achieved channel sealing when using high PAM dosage rates and interest in PAM for similar applications has increased. Whilst a number of trials have demonstrated some degree of seepage control overseas, there has been little well documented research under local conditions.

It is believed that PAM acts to reduce infiltration by flocculating suspended sediment which settles to the bottom and forms a semi-impervious sediment barrier. It is therefore likely that the effectiveness of this technique will depend on the nature and quantity of suspended sediment. Results from [trials of PAM application to canals in the USA](#) have shown immediate seepage reductions from zero (no measurable seepage reduction) to as great as 90 percent. The duration of seepage reduction ranged from one month to as long as five months. However the level of immediate seepage reduction did not necessarily equate to net seepage reduction over an entire irrigation season.



PAM is most often applied in one of three ways:

1. As a solid, directly to the water surface of a body containing water.
2. As a solid, broadcast over the soil surface of an empty storage/channel and subsequently incorporated into the surface layer.
3. As a solution, sprayed onto the soil surface (most typically in channels).

The US NRCS standard for PAM application for canal treatment suggests that the PAM must:

- be anionic
- have a charge density of 10 to 55% by weight
- have a molecular weight of 12 to 24 Mg/mole
- be designated as “water soluble”, “linear” or “non cross linked”

As with bentonite and compaction treatments, [PAM was trialled](#) on a number of Darling Downs soils using in-situ ring infiltrometers and laboratory tests in 2005/06. The infield tests involved installing ring infiltrometers into the base of 4 different storages and applying PAM to the ponded water at a rate of 60 kg/m<sup>2</sup>. The results showed a reduction in seepage of between 30% and 75% as indicated in Table 1.6.12. It should be noted that the application was not replicated and the results may not be scientifically rigorous.

Table 1.6.12 - The effect of PAM application on four Darling Downs storages. Source: Hare (2006).

	Storage 1	Storage 2	Storage 3	Storage 4
Seepage before mm/day	6.72	6.64	58.33	27.51
Seepage after mm/day	3.14	3.05	39.35	6.74
Reduction %	53.3	54	32.5	75.5

Laboratory testing of polyacrylamide was also conducted on three Darling Downs soils (Campin, 2007). A PAM application equivalent to 60 kg/ha was applied as a solution to the soil surface. The reduction in hydraulic conductivity ranged from less than 10% up to 80%, although three quarters of the tests had results of less than 40%.

A 2011 trial of PAM on an entire storage with seepage of 15 mm/day did not provide any significant reduction in seepage, although this trial was not scientifically rigorous (see [Seepage Remediation Case Studies](#) p. 14).

## Synthetic liners

Many commercial liners of varying strength and durability are available to seal dams including woven polythene, black polythene, vinyl, high density polyethylene (HDPE), butyl rubber, polypropylene and bentonite composites.

The soil that liners are placed upon must be compacted, even and free from sharp objects such as stones and roots that may damage the liner. The underside of the liner must remain vegetation free so the soil is sometimes sprayed with herbicide to prevent any plants growing and penetrating the liner. The liner must be secured, which is often achieved by burying the liner in a trench around the perimeter of the storage.

NSW DPI AgFact AC.24 provides the following information about specific liner materials:

*Woven polythene, in blue or green, resists tearing but is very susceptible to UV degradation. If it is not protected from sunlight with a layer of soil, it has a very short life. Woven polythene is very unlikely to last 5–7 years in the sun. A grade no steeper than 3:1 must be used to keep the soil from slipping off the liner.*

*Black polythene also has a short life due to UV degradation. It is also quite thin, generally less than 0.4 mm, and is susceptible to puncturing. It must be covered with a layer of soil to prolong its life. There are two grades of black polythene. One uses reprocessed resin and the other uses prime resin. The prime resin liner lasts longer than the reprocessed resin liner. Also, the thicker the liner, the longer it will last, because it is better able to withstand the continual UV degradation of its surface.*

*Vinyl (or PVC) resists tearing and is more flexible than woven polythene. Again this material needs to be covered with a layer of soil to protect it from sunlight.*

*HDPE has a longer life and is tougher than vinyl or woven or black polythene. It resists tearing and does not need to be protected from UV exposure.*

*Butyl rubber is also resistant to sunlight, is flexible and very tough. Both HDPE*

*and butyl rubber are more expensive than vinyl and woven or black polythene. Composite materials contain a thin layer of bentonite sandwiched between polypropylene material. They are not UV sensitive. Because of the bentonite material, small ruptures in the liner are self-healed. However, these liners must be covered with soil to protect them from major punctures.*

[Western Australian Department of Agriculture Farmnote 5/2003](#) suggests that the best available membrane lining materials are polypropylene and high-density polyethylene (HDPE) which can both be stabilised to withstand the effects of ultra-violet radiation. When installed to specification, an exposed liner of polypropylene 1 mm thick has a life expectancy of at least 17 years, and an exposed liner of 1.5 mm HDPE has a life of 20 years. However these lifespans only account for UV degradation, not physical damage.

Synthetic liners are more or less impermeable and should provide seepage reduction in excess of 90%. The effectiveness of liners will largely depend on ensuring that they do not become damaged, which is of particular concern for cotton storages which are frequently empty. The liner may be susceptible to damage by animals, vegetation and storms during these periods and options to prevent potential damage will need to be considered. A minimum liner thickness of 2 mm is recommended to help resist physical damage. A soil covering may be most helpful to reduce animal and storm damage although the likelihood of damage by vegetation may increase. Furthermore, a soil covering may increase the difficulty of identification and repair of any areas that do receive damage. Maintaining soil coverage on batters may also be difficult.

## Determine the cost effectiveness of solutions

In most situations, one or more of the seepage or evaporation mitigation strategies discussed above could be applied to an individual storage and would be expected to achieve effective water savings. However, investment in one of these strategies must ultimately be made in terms of whether the water can be saved economically. By the time you get to this stage, you should have:

- Measured your seepage and evaporation losses.
- Examined the potential seepage or evaporation mitigation options.
- Selected those that would be most likely to provide effective reduction of seepage and/or evaporation.
- Ensured that these selections are able to be installed on your storage.
- Understood the practical considerations of the particular technique, including the ongoing management and maintenance requirements.

It is now important to determine how economically each method is able to save water. This requires determining the total cost of the particular mitigation option as well as the likely amount of water that will be saved. [The Evaporation and Seepage Ready Reckoner](#) is an online tool which enables a basic economic analysis. Depending upon the complexity of your particular situation, it may also be worthwhile engaging a specialist consultant.

## Evaporation and seepage ready reckoner

[The Evaporation and Seepage Ready Reckoner](#) undertakes two major tasks:

- Firstly, it determines the typical amount of water loss from a storage. To do this, it requires the storage geometry or surface area data and, on a monthly basis, an estimate of how frequently the storage holds water (proportion of years the storage has water in it) and how much water would typically be in the storage.
- Secondly, it uses information about the selected evaporation and/or seepage solution to determine how much water would be saved, to calculate the Net Present Value of the strategy and to determine how cost effective the strategy is in terms of cost per ML of water saved.

To use the ready reckoner, a user is required to enter:

- The storage geometry or surface area data. This information is used to model the actual surface area for a given depth of water. Irregular shapes can be accommodated by simply entering the surface area at the top water level and of the base.
- Monthly evaporation. This information is easily selected using an interactive map.
- An estimate of the amount of water typically in the storage in each month.
- An estimate of the percentage of years that water is in the storage for each month.
- Seepage rate information (if known).

- Data about the evaporation or seepage mitigation system to be evaluated. This typically includes the predicted effectiveness of the solution, the capital costs, expected lifespan and on-going maintenance costs.

The Ready Reckoner can handle a wide range of evaporation or seepage solutions including:

- Split cells
- Increase wall height
- Continuous floating covers
- Modular covers
- Chemical covers
- Suspended covers
- Impermeable liners
- Clay liners
- Bentonite
- Polyacrylamide (PAM)

It is also possible to use both an evaporation and a seepage solution at the same time.

The economic analysis undertaken by the Ready Reckoner involves calculating the net present value (NPV) of the capital and on-going costs associated with the chosen solution. This value is then annualised over the lifespan of the works and this annual cost is compared to the amount of water saved per year.

It should be noted that in practice, the amount of water saved each year will vary depending upon the amount of water in storage and the actual climatic conditions encountered. The Ready Reckoner operates on the basis of a typical water holding pattern, in other words, the average amount of water that a storage would hold over a long period of time. It is therefore important to enter this information correctly.

A [recent analysis](#) of cell division and wall height strategies on 15 storages demonstrates how the Ready Reckoner may be used. This publication includes a flowchart which explains the analysis procedure and demonstrates the impact of different water holding patterns on the cost effectiveness of solutions.

## Storage maintenance

Prevention is better than a cure! Simple storage maintenance and monitoring can sustain the efficient state of a storage and minimise the long-term costs of seepage mitigation strategies. Detailed information on storage maintenance is included in the [Guidelines for Ring Tank Storages](#). The major steps include:

- Visually inspect storages every one to three hours during filling and every two to four weeks during normal use.
- Take objective measurements (e.g. survey levels, GPS, crest width measurements, etc.) to identify storage changes over time.
- Maintain the crest, as it is typical for crest height to reduce over time due to erosion at up to 25 mm per year.
- Maintain batters by grading and rolling as necessary to prevent the formation of excessive rills, gullies, tunnels or wave erosion.
- Repair larger defects by excavating, replacing with moist soil and compacting. Placing dry soil into large defects is not a long term solution as this soil is easily remobilised and washed out.
- Keep storage batters and crest free of vegetation. Even grass has been found to seek out moisture from deep within storage walls during dry periods, leading to structural failures. Use non-residual herbicides and ensure no trees are placed within 15 metres of the toe of the embankment.
- Maintain the floor and borrow pit to prevent ineffective storage space (dead water). Manage dry storages to conserve soil moisture to prevent cracking and avoid the need for significant water volumes upon re-wetting. Avoid any vegetation.
- Fill storages with caution, especially after a period of prolonged dry weather. The guidelines contain further information about storage filling precautions.

### Case study, Dam evaporation and seepage mitigation trial

In 2001, a local Emerald irrigator measured losses of 1 m in less than a month from his newly constructed water storage. Aware that water storages were a source of large water losses on farm, and concerned by the losses he had experienced in his own operation, the irrigator teamed up with Emerald's water use efficiency (WUE) officer and water use efficiency researchers to quantify what was being lost, and what could be done about it.

An on-farm trial was designed to look at accurately measuring losses of evaporation and seepage from on-farm storages and to trial various commercially available tools for reducing seepage and evaporation. Eight 70,000 litre capacity dams were constructed, as listed below in Table 1.6.13.

Table 1.6.13. Trial dams

Dam	Size (m)	Treatment
1	4 × 4 × 4	uncompacted, uncovered (control)
2	2 × 8 × 4	compacted, deep and narrow construction
3	4 × 4 × 4	compacted, lined and covered (Figure 1.6.18)
4	4 × 4 × 4	compacted and top-covered
5	4 × 4 × 4	compacted and lined (Figure 1.6.19)
6	2 × 5 × 6	compacted, shallow and wide construction
7	4 × 4 × 4	treated with bentonite (sides and base)
8	4 × 4 × 4	compacted (base and sides)

Figure 1.6.18 Covered and lined dam. Polypropylene liner and polyethylene cover



## Case study continued

Figure 1.6.19 Lined dam



The eight dams were constructed by a private contractor who specialised in building dams. A sheepsfoot roller was used in those treatments that were compacted. Liners and covers were installed by Darling Downs Tarpaulins. In 2001 bentonite was incorporated into dam 7 as a mixed blanket and in 2002 bentonite was broadcast into the dam.

The trial was monitored weekly to measure evaporation and seepage losses. A water reticulation and float valve system was used to top up the trial water levels once a week. A weather station was erected at the site to monitor site conditions. Dams were filled and maintained at the expense of the irrigator himself. Dams 3 (covered and lined), 4 (covered), 5 (lined), and 7 (bentonite) were monitored using ultrasound equipment with the help of Queensland Natural Resources & Mines (NR&M).

Losses from evaporation and seepage that were recorded over a two-year period are shown in Table 1.6.14.

Table 1.6.14. Water storage daily losses (mm) from 2001 to 2003

Treatment	2001/02	2002/03
Covered and lined	4.73	4.55
Covered	10.53	7.44
Lined	6.86	6.18
Bentonite	29.13	55.58

The data for the two seasons show fairly consistent results, with the covered and lined dam retaining the most water, followed by the lined treatment. Water was lost more readily through seepage than through evaporation.

## Case study continued

The covers used for this trial were made of a plastic material with air pockets to keep it afloat and holes to allow rain through (E-Vap Cap®). Throughout the two seasons a number of technical problems occurred with the covers. In December 2002 the covers blew off during a storm and during the 2002/03 season silt and algae started to affect the covers' flotation. Further research and improvements are being undertaken by the National Centre for Engineering in Agriculture on these covers and other evaporation-reducing products.

### Cost of covers – \$6.60/m<sup>2</sup>, 5 year guarantee

The liner used was a 0.5 mm high-density polyethylene sheeting fusion welded to fit the dam. Holes have started to appear in the lining. It is suspected that kangaroos after having a drink may put holes in the lining trying to get out. Holes in the lining started to diminish the effectiveness of the lining, but it is still reducing water losses from the dam (Table 1.6.14).

### Cost of liner – from \$3.56/m<sup>2</sup> to \$8/m<sup>2</sup>, life expectancy 25-30 years

Bentonite was chosen, as it is a non-toxic, naturally occurring clay chemical compound sodium montmorillonite that swells when wet. This expansion helps to seal pores and cracks in the dams and water channels. Between the 2001 season and the 2002 season the dams were allowed to dry out, allowing cracks to appear. Cracks in naturally lined dams can cause weaknesses, increasing water losses when filled. The bentonite dam lost more water during its second season because of this problem. At the start of the 2002 season, water use efficiency officers broadcast bentonite into the dam. Broadcast is a recommended method of application, but in our trial it was not effective. Basic dam maintenance could have been used to minimise the losses such as maintaining a minimum water level and filling cracks.

### Cost of bentonite – \$15/40 kg

#### Mixed blanket – 7 kg/m<sup>2</sup>

#### Pure blanket – 10 kg/m<sup>2</sup>

In the first year of this trial the irrigator incorporated bentonite into the walls of his own on-farm storage in an attempt to reduce seepage. Due to the dam being regularly filled and emptied throughout the year, the irrigator is unable to maintain a minimum water level. Since the incorporation of bentonite, water has continued to be lost through seepage, but the amount of water being lost from the dam was reduced as a result of the bentonite. Water savings from bentonite will vary and for good results it is important that it is applied evenly, compacted and well maintained.

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