Seepage Remediation
Case Studies of Grower Practices

Case studies of projects by cotton growers
to remedy seepage losses from on-farm storages

Cotton Catchment Communities CRC

Australian Government
National Water Commission

NCEA

Contents

Acknowledgement

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Introduction

About the Project

On-farm water storages are an integral component of most irrigated cotton farms in Australia. However recent whole farm water balance studies have indicated that around 30 to 40% of all water on farm can be lost in storages. This comprises the biggest proportion of on farm water loss out of any component of the irrigation system.

To determine the extent of storage losses, the National Water Commission, through its Raising National Water Standards Program, funded the Cotton Catchment Communities CRC to undertake this project "Measurement to improve the water efficiency of on-farm storages in the cotton industry."

The project has used commercial consultants to determine evaporation and seepage losses from individual storages using the Irrimate™ Seepage and Evaporation Meter. The project has now measured over 135 storages to determine the magnitude of these losses.

To complement this new knowledge, the case studies in this booklet provide examples of works that growers have undertaken in the past to remedy storages with unacceptable seepage losses. As the causes of seepage issues are often difficult to identify, some of these case studies have been effectively resolved whilst others remain a work in progress. It is hoped that the lessons that these growers have been able to provide might help others who are also looking to remedy their own seepage problems.

Acknowledgement

Many thanks go to the growers and consultants who have provided very insightful information for these case studies and without whom this publication would not be possible. Also to the writers and photographers who contributed to this publication and to Broons for supplying images of their square impact roller.

Featured Seepage Remediation Options

This publication includes a range of works that growers have implemented in order to address seepage issues. Note that other options are available which may not be discussed here (for example plastic liners) although there were no examples of their use within these case studies.

Measurement and Identification

The first step in seepage remediation is identification of the problem. Measurement of seepage losses has traditionally been challenging as it is difficult to differentiate seepage losses from evaporation losses. For storages with very high seepage, this assessment is often made visually, as water levels may drop very rapidly over a period of weeks.

However, an accurate measure of seepage is still very useful for determining the cost effectiveness of possible solutions. Until recently, there was no widely available technology for undertaking such measurements. However a new technology, the Irrimate™ Seepage and Evaporation Meter, has been used with success within this project and is able to cost effectively separate seepage and evaporation losses within a storage.

Once a seepage problem is identified, the next challenge is determining the nature of the seepage loss. Evidence in the case studies in this publication suggests that most seepage problems occur in discrete locations within a storage, rather than uniformly across the storage floor. Such problems are often due to the presence of small sections of sandy or gravelly soil.

In many of the case studies, a combination of EM surveys and physical inspections (test holes or excavation pits) were used to identify these regions. As one of the case study growers noted, EM surveys can be very useful for identifying particular problem areas, but they are not completely foolproof, and ground truthing the results is important to ensure that potential issues do not go unnoticed.

Another method of investigation, resistivity imaging, was used by one grower to look at cross sections of soil profile in significant detail.

Clay lining and compaction

The most predominant type of seepage solution employed by growers involved the application of additional clay material over suspect areas, sometimes with additional compaction. Compaction of existing materials was also used on some occasions.

The case studies indicate that the methods for undertaking these works can vary significantly. The depth of clay lining varied from 0.25m up to 2m. Some growers chose to overlay this compacted clay with additional material of around 0.5m thick to prevent the compacted area from drying out.

Introduction

Compaction was provided by various means, with some growers relying on the compaction provided by earthmoving machinery (bulldozers, scrapers or laser buckets) whilst others applied additional compaction with sheepsfoot rollers or square impact rollers.

The level of compaction provided by different equipment should be considered when undertaking this type of work. In particular, tractors and bulldozers are designed to spread their load over a large area to avoid compaction and ensure traction. As can be seen in Figure 1, equipment designed for compaction, such as the sheepsfoot roller, provide many times more compaction than a bulldozer, even though the machine weight is lower.

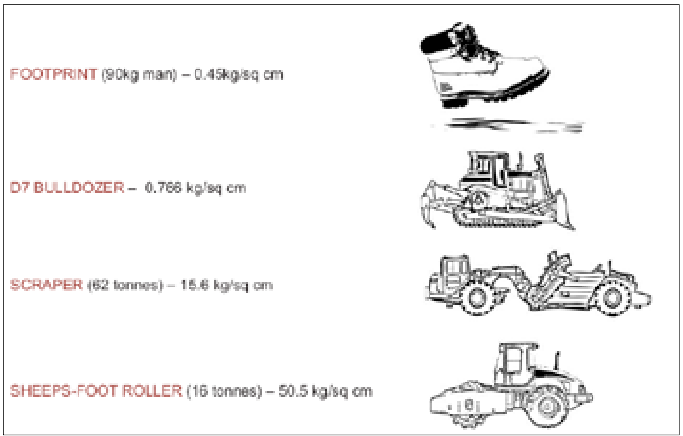


Figure 1 - Compaction pressures applied by different equipment (Source: Guidelines for Ring Tank Storages, Irrigation Australia Limited)

Soil type is also a key consideration. Many clay soils in cotton growing regions have a large shrink-swell capacity. Therefore if compacted clay is allowed to dry out, it will most likely crack open and the effectiveness of the compaction will be diminished. This is why some growers have chosen to overlay their compacted soil with additional material to try and prevent cracking.

Planting crops in empty storages will dry the soil more than evaporation alone and will almost surely reduce or completely remove the effectiveness of compaction. For this reason, planting crops in storages is strongly discouraged.

Bentonite

Bentonite is a type of clay which has a very large shrink-swell characteristic that results in a very low permeability when wet. Bentonite suppliers should be able to provide advice regarding the best application method for specific applications and soil types. The most common methods of application are:

- Pure Blanket – a layer of pure bentonite of around 10mm thickness is used with a protective compacted covering of soil.
- Mixed Blanket – Bentonite is incorporated into the existing soil at a rate of around 50 to 150 t/ha depending upon the existing soil characteristics.
- Broadcast – Bentonite is applied to the surface of a storage which contains water and allowed to settle to the bottom of the storage.

It is suggested that blanket techniques are more effective, with the potential to reduce seepage by 65 to 95%, whilst broadcasting is more likely to result in a 30 to 50% reduction. It is critical to ensure that bentonite is applied at the recommended rates and in the recommended manner as the results may not be satisfactory when the rate of application is too low. As with clay lining, a protective cover of at least 0.5m of soil is likely to improve performance and longevity.

Polyacrylamide

Polyacrylamides (PAM) are chemicals used in a variety of industries including the food and water industries. Specific PAM formulations, typically high molecular weight products, have been found to provide seepage reduction in some cases.

PAM can be applied to the soil surface, where it may or may not be incorporated in to the soil. It can also be broadcast over a body of water. Whilst evidence of PAM effectiveness exists, the only use of the product within these case studies does not seem to have reduced seepage loss.

The use of PAM may be of lower cost than some structural solutions, although the PAM is likely to need reapplication at regular intervals and the seepage reduction effectiveness may be variable.

Property: **Caithness, Moree**
Grower: **Kelly Humphries**

Background

In an effort to increase on farm storage after purchasing 'Caithness' northwest of Moree in NSW, owner Kelly Humphries selected an existing storage to renovate. The storage was relatively shallow and had an irregular shape that reflected the course of a nearby waterway.

Kelly says the original storage structure did not leak. However, when renovations to increase storage capacity were being carried out a few years ago, water was noticed seeping into the dam from a section of the storage floor that was adjacent to the river.

Prior to commencing renovations to the existing storage, Kelly commissioned SMK Consultants in Moree to carry out an EM-31 survey on the dam to check that the soil material was likely to be suitable. The EM-31 survey revealed some variation in the soil conductivity across the storage area. Immediately following the EM-31 survey, soil trenches were dug using a backhoe to approximately 3 meters to investigate the soils corresponding to different colours on the EM-31 map. These trenches did not reveal any soil material that would be unsuitable for holding water.

The Problem

Construction began to increase the storage capacity by excavating a further 1.8m of material from the storage floor and an additional 2.5m of material was added to the wall height. As the excavation was taking place, it was discovered that water was seeping into the dam.

The original EM-31 survey map was then reviewed and it was realised that some of the green areas on the south eastern corner of the map corresponded with the area where the water was being seen in the dam floor. Using the backhoe that was onsite for excavations, Kelly had numerous pits dug to investigate the soil at depth in those areas revealing a seam of sandy soil in that corner of the storage. It is believed that this sandy seam was part of a previous watercourse that ran underground through to the nearby riverbed and that water must have been seeping into the excavated area from the river. It was likely that once the storage was filled, water would move out of the storage in the same way.

The Solution

To prevent seepage from the renovated structure, the area in the south eastern corner of the storage, where sand had been found at depth, was clay lined. Suitable clay material was taken from other areas of the storage to create a 1meter deep lining which raised the storage floor to the height of the natural ground level outside the dam wall. The clay was spread using a laser bucket which Kelly believes also provided adequate compaction so no further compaction was required.

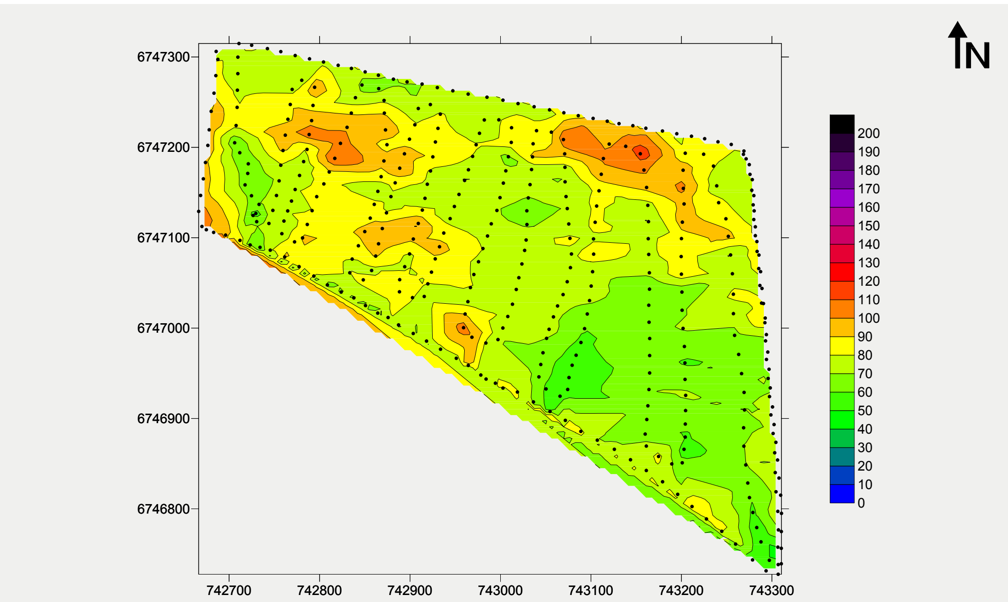
The Outcome

The dam currently has a water level of approximately 3m. Measurements taken recently by John Doble from Gwydir Valley Irrigators Association (GVIA) using the Irrimate™ Seepage and Evaporation Meter, indicate seepage to be approximately 200mm/year (less than 1 mm/day) demonstrating that the remediation work was successful.

The seepage remediation was estimated to have cost approximately $30,000 which Kelly says "was well worth the expense."

The Future

Kelly questions whether the rate of seepage will be greater when the storage is at full capacity but is happy with the outcome of clay lining.



Property: **Red Bank, Moree**
Grower: **Ray Fox**

Background

Red Bank is a property owned by Australian Food and Fibre located near Moree. The property's only on-farm water storage is 300 ML with an area of 12.5 ha. The storage is built on red clay over a sandy base and has a creek nearby. It is believed to have been constructed in the late 1980's and has been consistently used every year. It is usually dry for three to four months over winter.

The Problem

There was no abnormal water loss observed or recorded until around 2004/05 when it was noticed that the water level was dropping more than Ray believed could be attributed to evaporation. The change in water depth was measured and a loss of approximately 10mm/day was estimated.

Seepage was believed to be occurring in the vicinity of the original pump site which was moved in the late 1990's. Due to the nearby creek, visual evidence of seepage was generally not noticed. However, on occasion the outside wall would look damp low on the base of the storage to the east of the old pump site. Ray believed that the wall was not compacted sufficiently when the pump site was moved.

The Solution

Renovation work was initiated in 2005 to repair the area believed to be responsible for the leak. The storage was emptied and the inside wall adjacent to the old pump site was covered with 30cm of black clay which was cut from the storage floor. The work was completed using a laser bucket with no additional compaction of the clay. The storage was utilised immediately after the work was completed.

The Outcome

The renovation significantly reduced the seepage losses for the next 2 to 3 years. However, losses were again observed when the storage was filled for the 2008/09 season. Losses are again estimated at around 10mm/day and are evident when the storage is more than one third full. Ray initially noted that there did not seem to be any seepage occurring when the storage level was below one third capacity. However during November and December of 2010 Ray noticed that water losses actually seemed to be occurring regardless of the water volume stored in the dam.

The Future

AFF have now contracted surveyors SMK to conduct an EM survey. Soil pits will also be dug to identify the full extent of the problem. The intention is to repair the area identified in the EM survey with clay. They will also ensure that the clay is compacted more thoroughly than it was in 2005. This work is expected to take place during 2011.

Property: **Boolooroo, Moree**
Grower: **Ray Fox**

Background

'Boolooroo' is an irrigated cotton property north of Moree in the Gwydir Valley, which has been recently leased by Australian Food and Fibre (AFF). Manager Ray Fox noticed water levels on a 30 ha, 700 ML storage were dropping more rapidly than he believed could be attributed to evaporation.

The Problem

Ray observed that the storage lost water regardless of how full it was, which suggested to him that the seepage was occurring through the floor. He measured water height changes and estimated seepage losses of approximately 6 mm/day. The storage was built around 2001, but as 'Boolooroo' had only recently been leased by AFF, Ray was unsure of how long it had been losing water.

The Solution

The storage was emptied to allow soil pits to be dug and an EM survey conducted. It was identified that the water losses were likely to be attributed to some gravelly soil found on the storage floor.

In 2008, remediation work was initiated. The entire floor of the storage was covered with a 30-40cm layer of clay imported from elsewhere on the property. The spreading and levelling work was completed using a scraper to compact the clay. The storage was utilised immediately after completion of the work and has not been completely empty since renovations took place.

The Outcome

"To date the renovation has been successful and only evaporation losses are now being observed from the storage" says Ray.

Property: Located near Warren, NSW
Consultant: Pat Hulme, Sustainable Soils Management

Background

In 1994 a water storage dam was constructed on a property near Warren in NSW. Prior to construction, an engineering consultant was engaged to investigate the site and design a suitable water storage dam. Following a cursory inspection and 2 test pits, it was considered that material at the site would be suitable for construction of the water storage and a design was supplied.

Elevating bowl scrapers were used to construct the storage. Material for the walls was dug from a borrow pit and sourced from the cheapest sites to transfer soil from. A key trench was built approximately 0.5m deep under the walls around the entire perimeter of the storage. No additional compaction was carried out during this initial construction phase. The final storage was 650m by 290m with a 2m high wall and a capacity of 350ML. Within a few months of completion the water storage was filled.

The Problem

After the next season's cotton crop was planted, prolific growth of the cotton plants was observed in a specific area of the field adjacent to the water storage. The soil was boggy and wet and therefore it was assumed that water was somehow leaking from the newly filled water storage.

The Solution

In May 1995, Pat Hulme, a local soil consultant was contracted to assist in identifying the problem.

An EM31 survey was carried out which showed a strip of material with low electrical conductivity running through the water storage area. Pat followed up on this with permeameter tests, 5 test pits and more than 40 test holes.

The pits revealed sand at approximately 2m in some areas, but more than 3.5m of continuous clay in others. One test site had clay over sand whilst another site had sand over clay. It was surmised that water was moving through these sand layers into the nearby field.

A square impact roller was hired in an effort to compact the storage floor and slow seepage losses. However after refilling the storage, permeameter measurements confirmed that this had not been effective.

In 1996, to better understand the movement of water through the different sand layers, the Department of Land and Water Conservation drilled 6 test holes around the water storage and adjacent field to a depth of 20m or until the first aquifer was penetrated. The test holes were then monitored with piezometers. In some cases 2 pipes were installed 1m

Water leaks into the green area at the top of the photo, but not into the redder crop at the bottom of the photo

apart. In these cases, one of the holes measured changes to the deeper aquifer and the other measured changes to the water table closer to the ground surface level. It was hoped that this would reveal how well the two aquifers were connected.

The pattern varied between the sites. The water level rose very quickly in both piezometers in the part of the field that wet quickly (the blue area near the bottom right of the EM survey). The water level in this piezometer followed the storage water level very closely. In contrast, there was little movement in the water level of the piezometer in the dry part of the field (the yellow area near the bottom left of the EM survey).

These observations indicated that water from the storage was seeping through the floor material down to the underlying sand layers where interconnected local aquifers were present. It is thought that the sand layers are the remains of prior stream 'beach' areas where curves in the stream channel cause sand to accumulate inside bends and then facilitate movement of water underground. This explains the clearly delineated wet area in the adjacent field. Although the floor material was largely clay, it was allowing water seepage into the aquifer.

In this case, compaction alone, did not reduce seepage sufficiently to prevent the problem of water leaking into the field. "This is consistent with the general performance of compaction, which generally reduces seepage, but other than a few exceptions, does not stop it" says Pat.

The problem was managed for a few years by emptying the water storage in time to allow pick and other operations to be carried out. However, eventually it was decided to cut off the worst section of the water storage by moving part of the storage wall. The EM-31 survey map and test pit results were used to select the area of the storage to remove. The remediation design proved challenging as the leaky areas were running diagonally across the storage floor and around the inlet area.

A supply channel had to be constructed to take water to the new inlet area which meant crossing the area of sandy soil. Although this would be expensive it was realised that by reducing the area of problematic soil that required lining, clay could be brought in for the supply channel at less of a cost than lining the entire problem area if the wall was not moved.

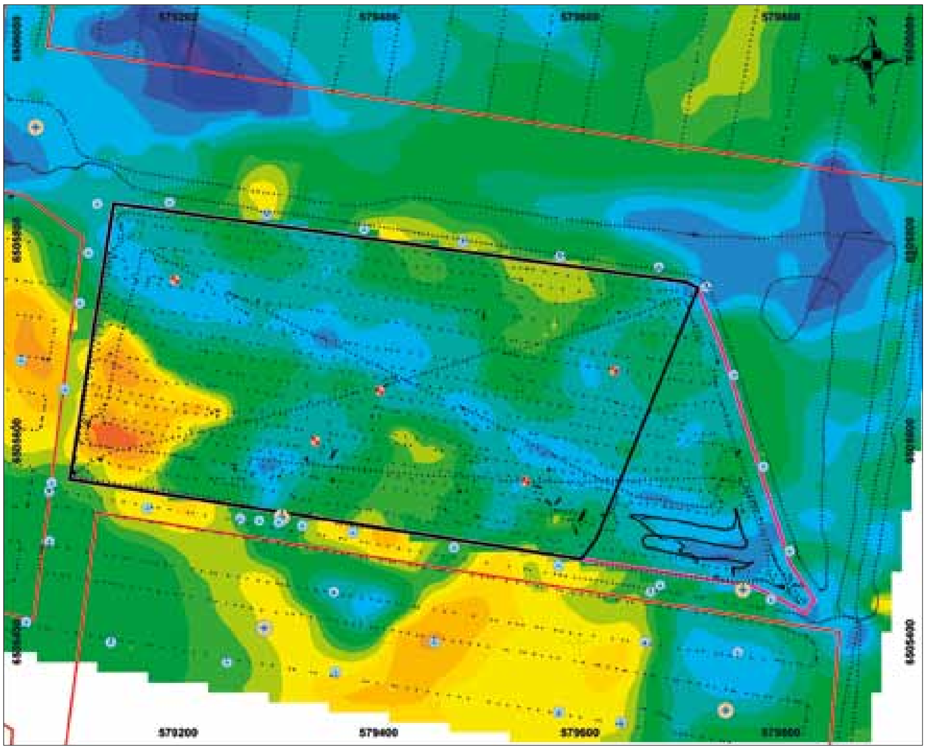
The site was remediated using elevating scrapers with 200mm lifts. Clay soil was sourced from an area adjacent to the reservoir and used to line the supply channel and a few small areas within the storage that were identified on the EM-31 map and test holes to have sandy soils.

The remediated areas of the storage and the supply channel were then compacted using a self-propelled sheepsfoot roller. To maximise compaction, the work was carried out when the soil was moist.

Capacity of the storage was reduced from 350ML to 300ML however seepage was no longer occurring.

The Outcome

Moving the wall, clay lining and compaction have successfully minimised seepage from this storage. Pat Hulme remarks that "It is important to note that the problem was found by soil coring different parts of the water storage and that the low conductivity results from the EM31 survey were caused by 2 different soil problems. One was sand over clay; the other was clay over sand. Where sand lays over clay there is likely to be a problem with water seeping through the storage floor and moving through the sandy layer. However, if there is relatively impermeable clay over sand, the clay layer is likely to prevent seepage into the sand layer. This can only be realised by soil coring areas identified as suspect from the EM31 survey."



Property: **Bethel, Moree**
Grower: **Mark and Peter Winter**

Background

Brothers Mark and Peter Winter farm three properties along Carole Creek, North West of Moree. On one of these properties, 'Bethel', they have 500ML and 2500ML storages. Whilst they believed the 2500ML storage held water quite well, losses from the 500ML seemed unaccepetably high, most likely the result of seepage loss.

The Problem

Construction of this storage started in the early 80's when Peter and Mark started to push up the walls with dozers. While working in the area of the North West corner, they discovered a seam of gravel which would not have been suitable material to have the storage built upon.

They proceeded to bore a number of holes inside the proposed wall location. From these holes, they determined that if they were to cut the corner off the proposed storage design, they would be able to move away from the area of gravel and have the storage sited on suitable clay soil. Hence by the late 80's they had a new storage design that had a wall approximately 100m from where the original corner would have been. Scrapers were brought in to finish wall construction and ensure appropriate compaction of the clay core in the wall.

However, once the storage was filled, it appeared that seepage could still be a problem. By measuring the change in depth of water over a period of time, Peter determined that perhaps the storage was losing 20ML of water per week . He believed that this amount would be well in excess of the potential loss to evaporation, indicating that some seepage must be occurring.

Furthermore, evidence of moist soil was occasionally noticeable at some points outside of the storage, near the base of the wall. This occurred not only in the corner of the storage near where the gravel had been previously found, but also along other sections of wall altogether.

The Solution

In around 1994, the Winter's brought in a square impact roller to provide some compaction over the storage base. The entire storage floor to about halfway up the batters was first ripped to a depth of 14 or 15 inches (350 to 380 mm). Then the square impact roller was used over this entire area to provide compaction. Mark notes that in some areas of lighter red soil, 3 passes of the impact roller was sufficient to provide substantial compaction. At this point, the roller was providing little additional compaction with the force of the strike being passed through to the tractor.

However the black clay areas required 7 passes of the impact roller to provide similar compaction. In this same soil type, the roller was also used to compact a section of channel, where the compaction resulted in a drop of the channel soil height of around 8 to 10 inches (200 to 250 mm).

Following the use of the impact roller, Peter recalculated the losses, and judged that the total loss was more or less halved, but was still not satisfied that the seepage was completely under control.

Some years later, an EM survey was completed to see if any significant soil differences could be identified which might be causing seepage in particular areas. The EM survey indicated that an area of lighter soil in the North West corner might have an increased potential for seepage.

This time, Mark and Peter tried using Bentonite, as this was more cost effective for a smaller area than the use of the impact roller. Bentonite was spread over this area and offset discs were used to incorporate it into the soil, before their own machinery was used to provide some compaction.

The Outcome

Although the seepage has been reduced since the storage was first constructed, Mark and Peter are still not satisfied that they have completely rectified the seepage problem, and therefore this storage is not regularly used. They are currently carrying out further works to minimise losses through more efficient water transfer between storages.

Property: **Baroma Park, Moree**
Grower: **Gary Taunton**

Background

The water storage at Baroma Park was constructed in the mid 1980's. It is an 800 ML storage, with 3.5 to 4m high walls. It was built on alluvial river flats and originally had trees growing in the storage at one end.

The Problem

Sometime between 1985 and 1989 a wall was constructed across the centre of the storage. This was constructed as water was seeping from the end of the storage which contained the trees.

In 1989 after Gary had purchased the property he siphoned water into the problem area of the storage. Gary found that the storage did not hold even 1m of water for a week. There was no evidence of water outside the storage so he concluded that the seepage was going directly down.

The borrow pit in this part of the storage was particularly deep, almost 2m deeper than the floor. Gary also observed that the soil in the borrow pit was more gravely than the remainder of the floor area. It is possible that the borrow pit extended into an old river bed.

Because of the high losses, this part of the storage was not used again until after renovation could take place.

The Solution

In 1991 Gary renovated the storage. The trees were removed and the borrow pit was filled with soil from the higher areas of the floor. The work was done with a scraper with no additional compaction. At the completion of the work the floor was even and it sloped to the pipe through the dividing wall. A gate was installed in the pipe to enable water management.

The Outcome

The renovated area of the storage was filled straight after the work was completed and has been used continually ever since. The storage is used to hold both bore and river water so there are constant changes in the storage during summer.

During autumn there is normally no water added to the storage. Gary has noticed during this time that there are some minor water losses which may possibly be more than expected from evaporation alone. However they are only very minimal and have not been measured.

Property: **Balmoral, Brookstead**
Grower: **Russell Clapham**

Background

'Balmoral' is an irrigation property located near Brookstead on the Darling Downs. It is owned and operated by the Clapham family. Russell Clapham has been growing cotton for 20 years, with irrigated production for the last 13 years on 'Balmoral. The soils on 'Balmoral' are cracking clays typical of the region. The property has four storages which currently all lose water at similar rates.

The Problem

When the Clapham family purchased 'Balmoral' 13 years ago, a 500ML, two-celled water storage had recently been constructed. However, the previous owner reported that the storage was leaking. One cell had much higher seepage losses, losing more than double the amount from the other cell. While Russell did not have any evidence of the extent of the leakage he decided to try and identify the cause of the seepage loss before filling the dam.

An excavator was used to dig pilot trenches to explore the base of the dam. A sand bed was found approximately 1.5 m below the surface of the dam base. This sand bed was at least three metres deep and originated from a prior stream adjacent to the storage.

The Solution

Once Russell had identified the sand bed he decided to line this area with clay. Clay was sourced from another area of the storage that was identified to be stable and have good quality clay. He layered 600 mm of this clay over the sand bed. This clay layer was then compacted using a Broons square impact roller. An additional 400-600mm of soil was then layered over the compacted clay liner.

Russell carries out opportune maintenance on the dams to further minimise seepage losses. When the dam is empty and they receive sufficient rainfall to wet the base of the dam he will compact the base by trafficking with tractors to help seal it. He finds that this is effective ongoing maintenance to help reduce seepage losses but it does not fix the problem.

He performs a similar operation around the banks of the storage if it has been dry for extended periods. A tractor with wide spread duals will be used with one wheel below the water surface to compact the bank around the water level.

The Outcome

The clay lining to address seepage losses was moderately successful for a limited time. It reduced the seepage losses for three years before the storage started leaking again.

It is estimated that the storage is currently losing approximately 13 mm per day. This is based on dam water height losses over the five months of March to July 2010. According to Russell the storage lost 2 m in height during this period. It is likely that losses from the storage will be greater over summer months as evaporation losses increase.

The Future

The next step is to identify more precisely what component of the losses is due to seepage and what is due to evaporation. This will require some more detailed monitoring of the dam using technology such as the Irrimate™ Seepage and Evaporation Meter, which was used to undertake these types of measurements in the Cotton Storages Project. Other options to stop the seepage may then have to be identified. Russell says that he "will have to stop the seepage but first I need to know what is seepage loss and what is evaporation loss"

Property: **Fairford, Moree**
Grower: **Stephen Seery**

Background

Stephen Seery recently renovated a 25ha on-farm storage as he changed the storage configuration on his property 'Fairford' in the Gwydir Valley. The original storage, which had been built around 1980, did not have a seepage problem.

The Problem

Prior to commencing the reconstruction in 2007/08, Stephen had an EM survey carried out to assist with identifying areas of soil that may not have had good sealing properties. Stephen also dug a number of soil pits up to 3 meters using a backhoe as he suspected that there may have been gravel on the dam floor that was not showing up on the EM survey. The soil pits confirmed Stephen's suspicions.

Gravelly soil was found using soil pits in places that had been identified as suitable for use in the EM survey. Stephen says he believed that "An EM survey could alert you to possible problem areas, but would not necessarily identify all the potentially problematic soil types as demonstrated in this case."

The Solution

During construction it was ensured that they left 1 meter of clay cover over any of the areas where they had identified unsuitable gravelly soil. In other areas of the storage, the floor was dug out using bulldozers to a depth of 1.8m below the original floor. Scrapers were used to finish the storage and no other compaction was carried out.

A few months after construction the storage was trialled with approximately 1300 ML of water, filling it to ground level. The water level dropped significantly over the following 2 weeks so it was decided to move the water. Stephen estimates approximately 300 ML was lost during this short time.

Once the storage was empty Stephen was able to visually determine where on the floor the seepage was occurring. On the inside of one wall at the bottom of the batter and across the borrow pit there were a series of sink holes, approximately 5-10 cm deep, with smaller tunnels off these.

Investigation of these sink holes with a soil probe indicated that there was a layer of gravel underneath these depressions. To identify all the problem areas the whole floor of the storage was visually assessed and probed, which confirmed the presence of gravel at a number of other sites.

To remediate the problem, 1 meter of black clay sourced from outside the storage was back filled over the gravelly soil areas. Clay was also added across the remaining area which was cut deeper in the initial development. In total, the remediation work required 50,000 cubic metres of clay. A 70 tonne bulldozer was used to spread the clay but no further compaction was undertaken.

The Outcome

The storage has now been filled over the 2010-11 season since the seepage remediation was completed. Unfortunately the seepage has been slowed down but has not been stopped completely. Inspecting the storage again has indicated that the work that was undertaken was successful, but that there were some other areas in the storage which were missed during the previous inspection. Stephen believes that if he now goes back in and completes the same work in these areas, the problem will be solved.

Stephen comments that in hindsight, "the ideal situation would have been to have avoided the seepage completely by not digging down the 1.8 meters".

Property: **Brighann, Moree**
Grower: **Michael Seery**

The Problem

A 500 megalitre storage constructed in 1985 on Michael Seery's property 'Brighann', west of Moree, was known to have a seepage issue. Filling the storage beyond 50% of its capacity caused the water height to drop more quickly than could be attributed to evaporation alone. Furthermore, as the water height was dropping, a wet patch became evident in the field next to the dam. As the water in the storage increased to 75% of capacity the water level decreased more rapidly and the wet spot in the field became more obvious.

In 1998 Michael began to address the seepage issue in the storage. Additionally, it was decided to increase the storage capacity to 700 megalitres and improve the efficiency with which it could be drained.

Prior to commencing the renovations, an EM survey was conducted across the floor and around the perimeter of the storage. The survey identified sandy patches which were generally found to correspond with low spots across the storage floor.

The Solution

The entire floor of the storage was lined with 1 meter of black clay sourced from outside the storage. The low spots on the floor where sand was identified in the EM survey were lined with a thicker 1.5 - 2m of clay. The whole floor was then compacted with a sheepsfoot roller. The wall height was increased by approximately 1.5m and the batters were improved.

Refilling the storage began soon after construction was completed. As the water level reached approximately 50-75cm, fifty tons of bentonite was applied by plane over the 20ha area of the storage (a rate of 2.5t/ha). The objective was to create a laminate across the whole storage floor. The storage was then filled completely.

The Outcome

Michael says "The renovation work has slowed the leak but has not stopped it." The work seems to have stopped the seepage losses when the storage is up to half full. However, above this level seepage losses still occur and there is still evidence of moisture in the field next to the storage, although the rate of loss is significantly less than prior to the renovations. At 75% capacity in the renovated storage, the water level is the same height as when the original storage was full. The wet spot in the adjacent field now becomes more evident as the storage capacity increases above 75%.

The Future

Given the current inconsistency in water availability there are no plans in place to do more renovations. Should conditions change Michael believes there are several alternatives which could be considered.

Firstly, more bentonite could be added. However he is not confident that this would be successful. Secondly, another clay layer could be applied although the cost of moving additional clay and the reduction in storage capacity make this an unattractive solution. Thirdly, there is the potential of lining the floor with a plastic membrane. However, he is not sure that this would be an economically viable option.

Property: **Located near St George, Qld**

Background

This family owned and operated dryland and irrigation property is located north of St George. Production consists of primarily winter crops such as wheat and chickpeas with some peanuts, cotton and mungbeans. Water storage tends to be only short term.

The Problem

This property has a 1000ML dam that was constructed after the family purchased the property. Whilst it was known that there was soil of marginal quality for the construction of the dam, the plan was to have a shallower dam so that they did not excavate deeper into this marginal soil. However during construction, excavation occurred in this marginal soil type which has resulted in subsequent seepage problems. Despite only being used for short term water storage, as much as half of the water pumped into the storage was being lost before the water could be used. The grower believed that the site of the problem was in the borrow pit, which is approximately 5 hectares and over 1 metre deep.

Local irrigation consultant Justin Schultz, Waterbiz

The Solution

The grower has tried different options to fix the seepage losses. The first attempt involved lining the borrow pit of the dam with 100 tonnes of Bentonite, which was applied as a pure blanket. Approximately 2 hectares of the borrow pit had double the rate of Bentonite applied (approximately 30, 000kg/ha) where the grower believed the leakage was more severe because of the soil type in this area.

The thickness of the Bentonite was approximately 5mm as it was not cost effective to increase the application rate to achieve greater thickness. The Bentonite was spread using a Marshall spreader to achieve good coverage. Once spread, the base of the dam was given a light harrowing and then filled with water. The Bentonite lining was not successful in fixing the problem.

The second attempt involved lining the base of the dam with black clay. The entire base of the dam was lined with greater depths applied to the borrow areas. In the borrow areas the clay lining was to a depth of 450mm. The rest of the dam base was lined with 250mm. The clay material was not compacted when it was first layered. It has since been compacted using a 25 tonne trailing sheepsfoot roller.

The grower currently carries out opportune maintenance of the storage base when empty. If sufficient rainfall is received to wet the base of the dam, the grower will compact it using a square impact roller to help seal the base. While this maintenance is carried out when moisture is sufficient on average this is undertaken twice each year.

The square impact roller is run over the base of the dam multiple times until compaction is to a point that the grower thinks is satisfactory. This is assessed using a spike. To achieve this level of compaction six passes of the roller is usually required. This maintenance program helps to reduce seepage losses but does not fix the problem.

In 2005 the grower had an EM survey conducted on the base of the storage to identify the leaking areas. The borrow areas in particular were identified as being prone to seepage losses confirming the growers suspicion that this was the area that needed to be addressed. The rest of the dam base was identified as suitable material for water storage. It appears that in the borrow pit area, removal of the suitable material had exposed more marginal soil underneath.

The Outcome

Both the Bentonite lining and the black clay lining reduced the seepage losses but did not fix the problem. The grower has used gauge board readings to estimate losses at an average of 12mm per day during the autumn and winter months (March to July). Specialist irrigation consultant Justin Schultz from Waterbiz, has estimated that approximately 3.5mm per day is due to evaporation losses and the rest is due to seepage.

The Future

The grower believes that the next step to address the seepage issue is to groundtruth some of the EM survey work. The EM survey report outlined further options that could be undertaken to minimise seepage from the storage.

One option is to increase the depth of the clay lining. Another is to use a lower permeability lining material to further line the dam. The black clay that has been used to line the dam is very suitable for agricultural production and has good structure which limits its suitability as a lining material. It was not originally compacted and it also contains weeds which dry and crack the lining material allowing water through the liner.

The grower believes that he "will have to get some professional help into the future and that there is some great stuff in the EM survey report that they could look at trying."

Property: **Kensington Park, Dalby**
Grower: **Ian Hayllor**

Background

Ian Hayllor grows irrigated and dryland cotton and grain crops on his property on the banks of the Condamine River, west of Dalby. Over the years Ian has put a lot of time and effort into ensuring his farm is as water use efficient as possible, with much of that effort spent trying to reduce seepage loss from one of his on-farm storages. Ian has two on-farm storages on this property; his first was constructed in 1984 with a capacity of 500ML and the other was constructed in 1996 with a capacity of approximately 1500ML.

The Problem

After constructing his first storage, Ian monitored his water levels manually and determined that water losses due to seepage were unacceptably high.

Until recently it has been extremely difficult to measure the precise seepage rate of an entire storage, let alone determine the location of any specific problems. Ian has therefore tried to remedy the problem over a period of years using whatever new technology was available at the time.

When the storage was constructed, the material all seemed to be of a suitable nature, with sufficient clay to prevent significant losses, so Ian thought that perhaps there were one or more sections where a thin layer of clay disguised sandy regions under the surface.

The Solution

Ian used an excavator to dig down to in excess of 5 metres in a number of locations across the storage to determine any potential sandy areas, but found only one. He then ripped this area and added some additional clay material before compacting with a sheepsfoot roller.

Whilst this may have made some improvement, Ian was still unhappy with the level of loss, so over the next few years he repeated this process over much of the storage base. At one stage, in a section of the storage that typically stays quite moist, Ian found a small zone that appeared to be quite dry, perhaps indicating a sandy spot that allowed more drainage.

He excavated this spot and did find an area of almost pure sand below, so he subsequently covered this area with 1-2 metres of clay loam material and again compacted with the sheepsfoot roller. However yet again upon next filling the storage he was not satisfied that the seepage losses had been adequately addressed.

By this time, Ian had already built his second storage, and was happy that seepage in this storage was not a major problem. A recent measurement of seepage, undertaken using the Irrimate™ Seepage and Evaporation Meter as part of the Cotton CRC Storages project, has supported this view with seepage measured as less than 1mm/day. This meant that Ian was able to use his better storage on a day to day basis, only using the other storage sporadically as more water became available. Over the last decade, this has meant that his older storage has been unused most of the time.

During this period, as newer technologies became available, Ian employed some of these to try and determine where losses were occurring. He had an EM38 survey undertaken in 2005, which did not seem to indicate significant variation in soil characteristics. However high resolution resistivity measurements also taken around this time did provide a very high level of detail regarding differences in soil type for certain storage transects.

Ian has now used this information to perform additional clay lining and compaction activities in certain areas across the storage, this time using a square impact roller to try and provide further compaction than the sheepsfoot roller. Visually, the square impact roller seemed to provide significant compaction.

"Previously, the soil had distinct channels throughout which looked like water pathways, but after impact rolling, the soil was like plasticine, it was completely changed" said Ian.

One concern in shrink-swell soils such as these is that the advantage obtained through compaction might be easily lost the next time soil dries out and cracks open, so in this case about 6 to 8 inches of soil was placed over the compaction to try and protect and maintain it.

Unfortunately, Ian still does not believe he has got to the bottom of the problem. "I don't think we have slowed it down one little bit, there has to be somewhere that we haven't looked" he said. Ian measured the change in water level over a few weeks in October 2010. After accounting for evaporation losses at the time, he estimated the seepage rate was around 15mm/day.

Ian then tried broadcasting polyacrylamide (PAM), which is marketed as a potential seepage mitigation technology when used at appropriate rates. Unfortunately, the PAM application was also unsuccessful, with an accurate measurement of seepage conducted as part of the Cotton Storages Project immediately after the PAM had been applied confirming Ian's earlier estimation of 15 mm/day seepage.

The Future

Ian is disappointed that the PAM did not work, but was happy to give it a try. "If it had worked it could have potentially saved us hundreds of thousands of dollars, but now we'll go back to the drawing board and look for other solutions."

"The key is that we need to know how to invest our money when looking for potential solutions. The resistivity measurements seemed to provide good data, so perhaps we use EM to find potential problem spots and then something like the resistivity measurements in these areas to provide more detail."

Property: **Long Meadows, Bourke**
Grower: **Mitch Abbo**

Background

In 2003 Clyde Agriculture had access to a Broons impact roller and decided to compact several storage floors and to repair the damage caused to storage walls due to wash. The decision to renovate was opportunistic; there had not been any significant seepage issues observed.

The Long Meadows storage (cell 1) was one of the storages that was renovated in 2003. The storage has a capacity of 4,700 megalitres and covers an area of approximately 137ha. The wall height is 4.5m, with a water storage depth of 3.5m and originally a three in one batter.

The storage was constructed in 1990 and soil tests were undertaken at that time.

By 2003, there was considerable wash on the downwind storage walls. Soil was being washed into the storage which was starting to impact on the storage capacity and the road around the wall.

The Problem

The wash from the prevailing winds had started to significantly damage the downwind storage walls. It had removed a significant about of soil from the walls. A cliff face was starting to form and storage capacity was being lost. Additionally the road around the storage wall was being affected.

There may also have been some seepage from the storage floor, but there were no accurate measure of how much was possibly being lost. Some moisture had been observed outside the storage, which may have been due to seepage.

The Solution

The work focused primarily on the downwind storage wall where the wash damage was most significant. The original batter had been three in one. The renovations adjusted this so that the top two meters of the wall had a batter of five in one. The lower two meters had a batter of three in one. This was done to create more of a beach like effect. Soil needed to make these adjustments was sourced from the centre of the storage.

The Broons Impact roller was used across the entire storage floor. After the initial passes, holes were dug with an excavator in a grid like pattern. These holes were used to assess the effect of the roller passes and were focused primarily on the areas where Mitch expected losses could have been occurring. These locations correlated with where seepage had been observed in isolated points outside the storage.

The storage walls were not compacted because it was felt that there was not a lot to be gained by compacting a completed wall. They could not justify rebuilding the walls and compacting the core, as this may have created more issues and was not cost effective.

The Outcome

In 2004 the storage was filled to capacity. It remained with water in it until 2006. There was no seepage observed during this time, although no specific measurements were taken.

The storage was dry again for two years during 2007 and into 2008. During this dry cycle there was considerable cracking with cracks to a depth of at least one meter observed. The storage floor formed a block like structure. The blocks were quite well compacted but were broken by deep expansion cracks. There was an expectation for a reasonable amount of seepage.

In 2009 the storage was dry again. During this most recent dry cycle Clyde Agriculture sourced funding from the Western Catchment Management Authority. The funding was designed to do water balance calculations on farms. Additionally there was investment in metering equipment and information collected on the suitability of different soil types for storage construction.

During 2009 there were quite a number of measurements taken. There was an EM survey conducted by Terrabyte Services. Core samples were taken of the areas identified in the EM survey as suspect.

Additional to this a Geo Tech engineer used the EM survey as a basis to select sites for excavator pits. These pits were used to assess soil types, infiltration characteristics and the feasibility of increasing wall height and hence stored water depth. Soil samples were collected and soil analysis completed at each of the pits.

The 2009 funding provided for Irrimate Seepage and Evaporation meters, storage volume meters and mace meters for inlets and outlets.

The storage was again filled in late 2009. The seepage and evaporation readings indicate that seepage is very low (<1 mm/day) which gives Mitch confidence that the seepage is well within acceptable limits.

The Future

If Clyde Agriculture decides that there is a need to increase the storage capacity of the Long Meadows Cell 1 storage then the information collected on seepage and evaporation would be used as supporting data for an increase in wall height.

The most challenging aspect of storage management is maintaining compaction during the drying cycle. Most often wet conditions are preceded by extended dry periods, where deep soil cracks appear.