Monitoring Mallee Seeps Summary

Project 1569C for the

South Australian Murray-Darling Basin Natural Resources Management Board

Project Summary, June 2018

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In 2015, in a response to growing farmer concern, four seep monitoring sites were set up to assist both in our understanding of seep dynamics, as well as to explore practical farmer scale strategies that can be employed to successfully manage these issues.

At all sites there was a dramatic increase in the areas of seeps in recent years, with large areas of cropped land becoming saturated and often dominated by ryegrass, or becoming bare scalds. While this was mainly due to the very high burden of excess water moving through the catchments as a result of the well above average rainfall in 2016, there were also many other rainfall events over the three years that were found to contribute to the perched water tables beneath.

This project has clearly identified that the deep, non-wetting sand hills and sandy rises which have very poor water holding capacity, have been major contributors to seep formation. Rainfall events as little as 10-12 mm have been shown to be contributing significant recharge as water flowing down to the perched water tables above clay layers with very low permeability, that accumulate water, moving down slopes to discharge areas in swales, or where these clays appear between 1-3 m of the soil surface.

However, it is the larger rainfall events of 25-30 mm or more that tend to cause the greatest accumulation and surges in perched water tables at these sites, leading to a rapid increase in seep affected areas and discharge into the surface layers over an extended period. This results in permanent land degradation if no action is taken to strategically increase water use and prevent salt scald formation at these sites.

There are 4 main management strategies that have been employed within this monitoring project, including:

1. **Changing to a higher water use farming system**.
   Growing lucerne for hay has been clearly shown to utilize soil moisture levels to depth all year around, allowing them to absorb high rainfall events rather than contributing to recharge. The lucerne site was the only treatment to reduce the water table levels in 2016, despite the very high rainfall. Committing large land areas of productive cropping land to lucerne is not a suitable option for many farmers.
2. **Intercepting the lateral flow of moisture before it reaches the discharge areas.**
   Target strips of lucerne appears to be a very practical and effective method of intercepting subsoil water flows in sandy areas just above discharge areas, with 3 of the 4 monitoring site farmers now choosing to employ this strategy.

   Strategic tree planting can be applied where suitable within the landscape to intercept water movement through the catchment. It is however, very important to use the best establishment techniques in these areas which are often very sandy and prone to vermin attack. It is also vital to target the right areas, and a surface visual assessment of subsoil water movements is not always accurate. Understanding the salinity levels of the subsoil water is also important to make sure that suitable tree species are used.

3. **Ameliorating sandy soils to retain and utilize more water.**
   The spading of chicken manure has broken compaction layers on deep sandy soils, while increasing fertility, water holding capacity and productivity over a number of years, showing this to be an economically viable strategy. However, this treratment does have high upfront costs, which makes it difficult to apply over large areas of land. Accessibility to machinery and manures may also be an issue.

4. **Utilizing the excess water within the discharge areas.**
   Saltbush has been established within seep areas at numerous sites, along with Messina pasture, to both utilize moisture and provide soil cover to minimize evaporation and surface salt accumulation. Messina (and to a lesser extent Saltbush) has proved to be difficult to establish on the most scalded or waterlogged areas. Messina does not provide good summer cover, and therefore salt tolerant grasses such as puccinellia and tall wheat grass should also be considered.

   A new strategy of sowing summer crops into the specific saturated crop areas straight after harvest shows some promise. This aims to soak up excess water and prevent further land degradation by maintaining soil cover over summer. It does not address the issue at its source, and was not able to dry out saturated layers completely, but has allowed the farmers to manage the immediate impact of potential land degradation, while still maintaining their normal cropping program.

This project has proved to be a vital source of key information on mallee seep management strategies over a number of years. The findings have been used widely amongst many farmer and industry groups, and have also contributed to the development of further research and extension programs.

All of these sites and management techniques should continue to be monitored and analyzed in the next few years to increase our understanding of seep formation and the best ways to overcome this rapidly growing problem across our mallee lands.

2 Introduction

2.1 Background to project

The growing seep issues in the Karoonda district led to the establishment of four sites in 2015, and over the last 3 years has involved the use of soil moisture probes, piezometers and various soil water use monitoring to determine catchment management strategies. The body of information gathered, in conjunction with associated catchment assessment reports commissioned by the Natural Resources SAMDB, is contributing greatly to our understanding of how these seep issues are developing and what strategies may be employed to best manage and rehabilitate the problems.

This is the fifth report associated with monitoring the 4 seep sites between Mannum and Karoonda that were originally established under the "On-Farm Trials and Demonstrations to Address Seeps in the Murray Mallee" project funded through Natural Resources SAMDB.

Background to each site, EM38 mapping, soil tests and initial monitoring are contained in an earlier report entitled "On-Farm Trials and Demonstrations to Address Seeps in the Murray Mallee", by Chris McDonough, Rural Solutions SA in July 2015. The five following Monitoring Mallee Seeps Progress Reports, dated July-Dec 2015, Jan-June 2016 and July-Dec 2016, Jan-June 2017 and July-Dec 2017 provide analysis of monitoring of soil moisture readings, water table levels and the progress of various treatments at the 4 established sites. These Natural Resources SAMDB reports also provide some recommendations for future seep management. Reports can be found at http://www.naturalresources.sa.gov.au/samurraydarlingbasin/land-and-farming/soils/soils-resources.

After 3 years of monitoring the four sites over a range of seasons, rainfall events, and with various high water use strategies, valuable information for seep management across the Mallee is being understood and developed. Results and recommendations are regularly referred to at various farmer meetings, field days and site visits relating to the causes of seeps and management strategies that may be employed to best combat these growing problems within farming systems.

This report presents a summary of the monitoring findings in the context of what we have learnt from each site, and what is recommended to best overcome these issues for farmers.

2.2 Mallee Seep Formation

Mallee seeps form when excess rainfall passes through sandy surface soils and through the subsoils until they reach a layer of very low permeability such as Blanchetown Clay as shown in Figure 1. Water builds up above this layer and begins to move laterally to lower parts of the catchment. Where the low permeability clay appears within 1-3 meters of the soil surface in mid-slope areas (Photo 1) or at the bottom of swales (Photo 2), the topsoil becomes wet through capillary rise, causing the land to become waterlogged and bare out. This leads to surface salt accumulation over time, and total land degradation. When there is excessive water, particularly after large rainfall periods, these discharge areas become saturated and begin to pond with water, overflowing to lower areas in the catchment.

Figure 1. The formation of Mallee Dune Seeps near Karoonda (Hall 2107).

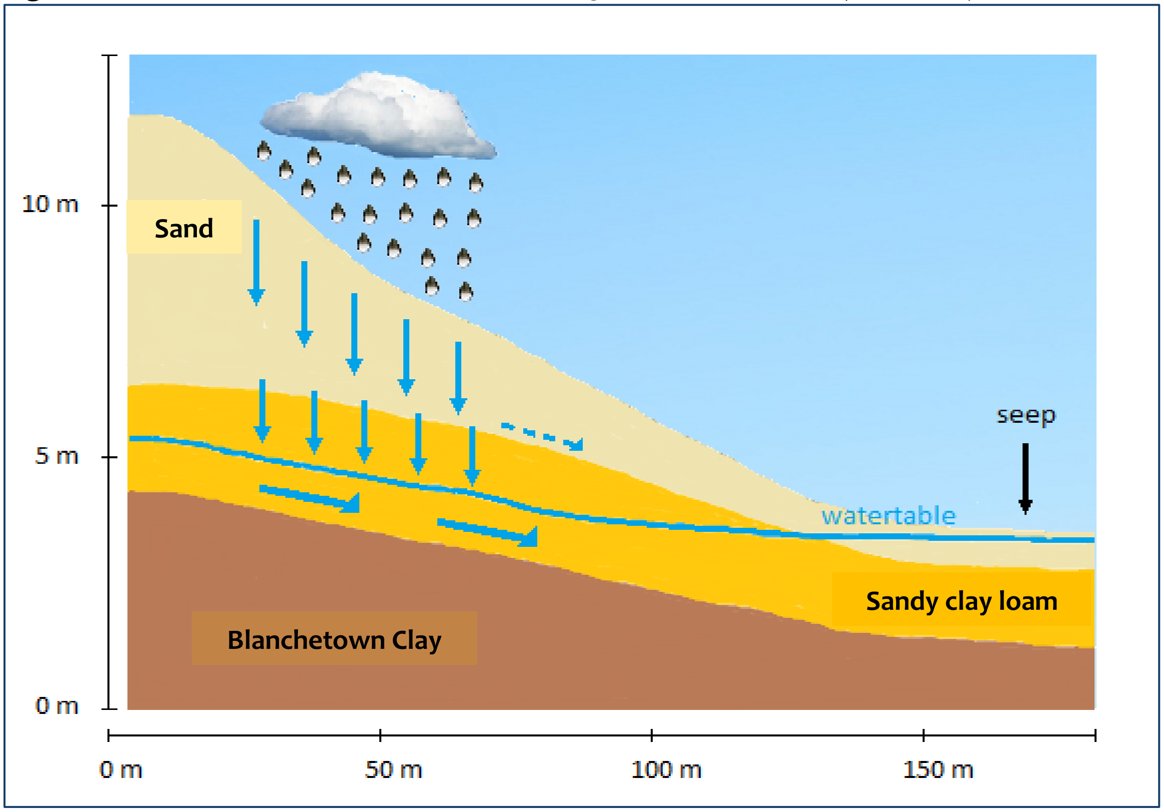


Photo 1. Mid-slope seep area at Arbons, where clay subsoils appear close to the surface.

Photo 2. Rose Seep formed at the base of a sandy rise

When drilling piezometers in the sandy slopes above the seep sites being monitored, the drill would usually pass through the sand profile and then the clay soil beneath, as can be seen in the site pit images (Photo 3). It would then reach a sloppy clay section representing the top of the perched water table, as shown in Photo 4. Below this was found to be a much dryer, lower permeability Blanchetown clay layer as shown in Photo 5.

Photo 3. Typical deep sand over clay soils contributing to recharge and seep formation.

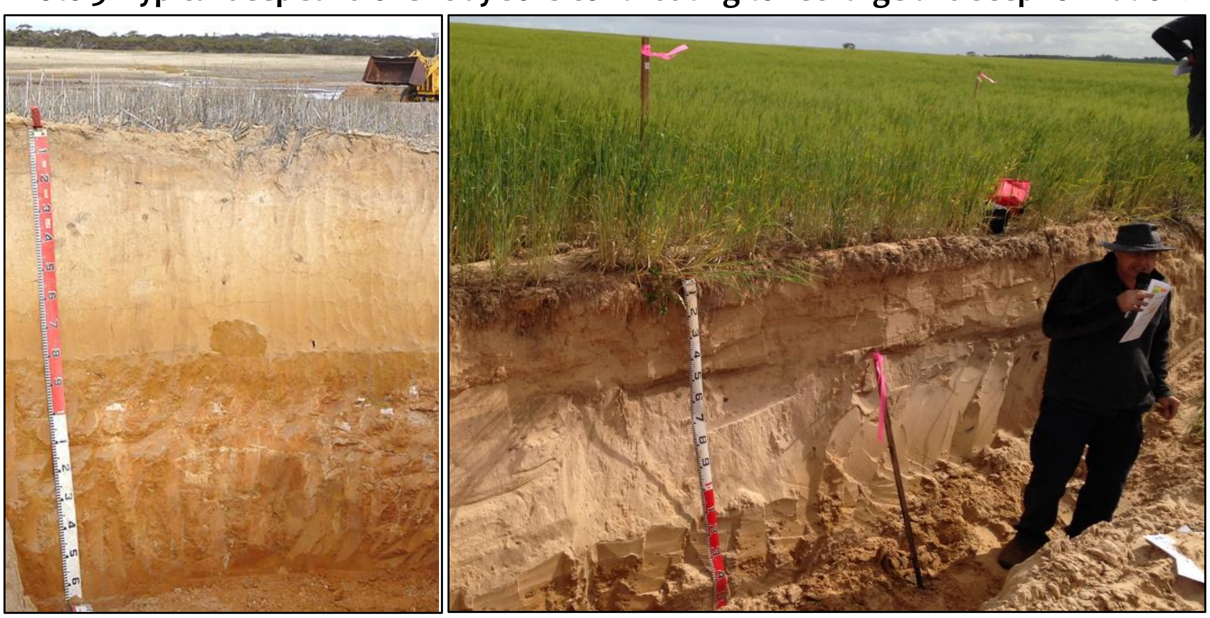


Photo 4. Sloppy clay indicating water table situated above Blanchetown clay layers

Photo 5. Blanchetown clay drill cores below sloppy clay perched water table.

Drill rig used for coring piezometer sites

SA Mallee seeps are generally found within the vicinity of deep non-wetting sand hills and sandy rises. The rapid onset of recent seep formation has occurred since the extremely high rainfall periods of 2010-2011 which had excessive rainfall in the non-growing season period, as well as 2016. The chemical summer weed control associated with modern intensive cropping farming systems has meant that far more summer rainfall is likely to contribute to recharge of perched water tables than under more traditional farming methods.

The Mallee Seeps Monitoring Project has been operating for approximately 3 years, assessing the "on ground" dynamics of four local seep catchment sites between Karoonda and Mannum, as well as trialing various seep management options to test both their effectiveness as well as practicality in being applied within actual farming systems.

This report aims to summarize the key findings that have come out years of site monitoring, while also expressing the needs for future work to increase our understandings of Mallee Seep dynamics and management.

3 The dynamics of Mallee seeps

3.1 Indications of the early stages of seep formation.

The early stages of mallee seep formation are usually indicated by soils below sandy rises having excessive water available within the plant root zone. This may be initially indicated by areas of high crop or summer weed growth as can be seen on Martins site in Photos 6 & 7. Checking the soil moisture level within the top 1 m of soil with an auger or soil probe can help to confirm this, and determine where saturated layers are found as shown in Photo 8.

Photo 6. Specific areas of summer weed growth at base of sandy rise, developing seep.

Photo 7. Summer weeds indicating new seep forming area in upper catchment

Photo 8. Saturated clay in developing seep areas at 70-90 cm depth.

As these areas develop with increased subsoil moisture, they can become vulnerable to heavy machinery causing serious and often unexpected trafficking issues (see Photo 9 & 10). This can become very costly and inconvenient to farmers in slowing operations, repairing equipment and having to avoid tracking through susceptible areas.

Photo 9. Tractor bog marks near Rose and Martin Seep areas.

Photo 10. Tractor bogged in a developing seep area in the Victorian mallee.

As the excess moisture is not usually saline at this stage of seep development, initially crop growth can be improved, as can be seen by the excellent wheat yield right next to a seep area at Arbons site, at the end of the very poor growing season of 2017 (Photo 11). However, as moisture levels increase, water can start appearing at the soil surface. As soils become saturated for long periods of time, this creates anaerobic conditions in the rootzone, leading to crop yellowing and plant death (Photos 12, 13 & 14). Ryegrass, which has a far greater tolerance of soil saturation than cereal crops, begins to dominate (Photos 15-17).

Photo 11. Improved wheat yield near Seep, utilizing excess soil moisture in dry season

Photo 12. Surface ponding after seeding at Bonds in 2017, following 2016 high rainfall year.

Photo 13. Crop beginning to yellow due to soil saturation in root zone at Bonds, 2017

Photo 14. Kevin Bond surveying rapid crop deterioration and bare scald development, 2017

Photo 15. Ryegrass beginning to dominate wheat crop in saturated areas at Arbons

Photo 16. Dominant ryegrass area at developing seep at Arbons site

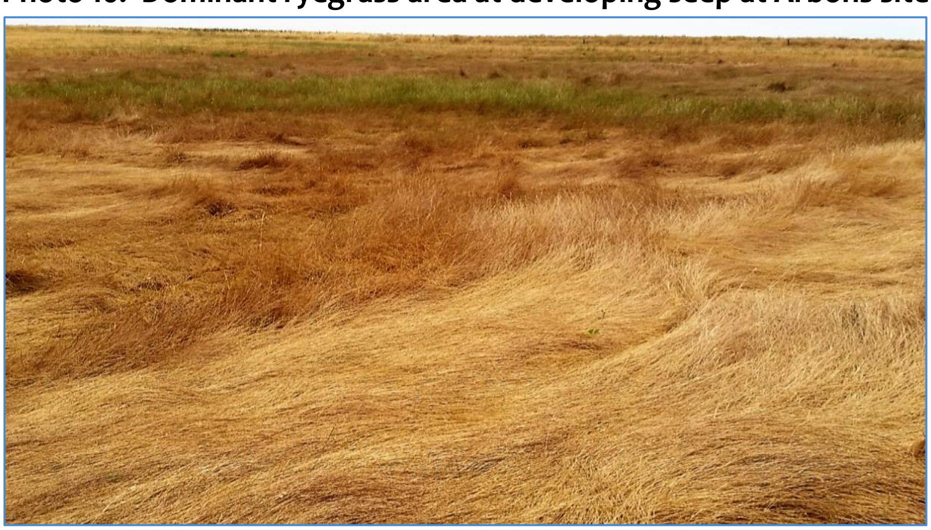


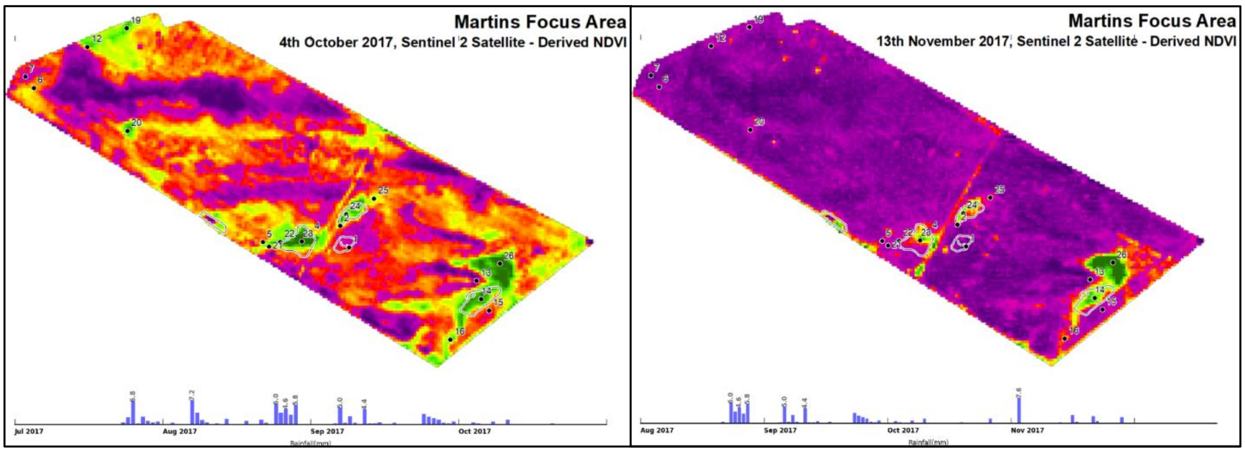
Photo 17. Poor wheat growth dominated by ryegrass competition in area below seep

Photo 18 clearly shows the progression of seep formation at the Rose/Martin site starting from the successfully ripened wheat crop behind, to the lingering green ryegrass dominating the fringe areas where both soil and water are not too saline. This is followed by the more salt and waterlogging tolerant volunteer pasture species, to the bare scalded seep where capillary rise and evaporation is causing salt to accumulate and crystalize at the surface.

Photo 18. Progression of seep formation, from wheat crop to ryegrass, salt tolerant pastures and bare saline scald

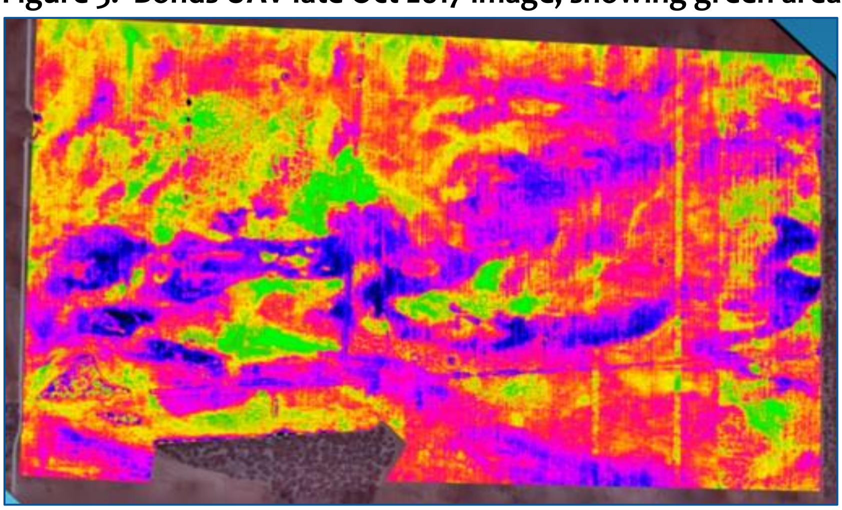
Normalised Difference Vegetation Index (NDVI) images have also shown to be very useful in identifying both areas under threat of seep development, as well as the extent of the areas that may be under threat. This is done by viewing the Sentinel 2 Satellite NDVI images at the end of the growing season when the crop areas have dried off, but the seep areas with higher moisture access remain greener for longer, as seen in Figure 2. These and other satellite NDVI images have generally revealed that the areas with higher soil water through to the summer period is far larger than ground assessments during the growing season revealed. These maps always need to be ground truthed, as specific colour changes may sometimes be due to a variety of reasons, but to date this technique has produced very promising results (Refer to McDonough (2018) Report for Natural Resources SAMDB).

Figure 2. Sentinel 2 Satellite NDVI image, revealing green areas of potential seep threat.



NDVI images can also be obtained using unmanned aerial vehicle (UAV) or drone mounted cameras. Figure 3 shows a drone NDVI image at Bonds, where the pink and blue colours represent deep sandy soils, while the green generally shows areas where the upper soil has remained saturated and maintained crop/weed growth. After harvest the Bonds targeted many of these areas strategically by sowing summer crops to help maintain cover and use up excess moisture.

Figure 3. Bonds UAV late Oct 2017 image, showing green areas of still saturated subsoils



3.2 Rainfall events that contribute to recharge on deep mallee sands.

This seep monitoring project has confirmed a number of factors that have clearly contributed toward the formation of Mallee seeps in recent years, including how relatively small rainfall events on non-wetting sand hills cause recharge, and how significant rainfall events in larger sandy catchments can lead to major soil water movement and discharge.

Figure 4 is a cross section diagram of the Rose/Thomas main seep area, showing piezometers at the top of the sandhill (RO1), the mid-slope (RO2) and the bottom of the discharge area (RO3). It also shows the level of the water table at the time of piezometer installation in 2015, as well as the layer of the low permeability Blanchetown clay beneath. Photo 19 shows the landscape with the seep and the piezometer locations at this site. The distance between RO1 and RO2 is approximately 60 m. These piezometers are perforated tubes sunk through the soil levels and constantly measure the rise and fall of the water table at these various sites within the catchment using data loggers.

Figure 4. Cross section of Rose/Thomas site showing piezometer locations (Hall 2015).

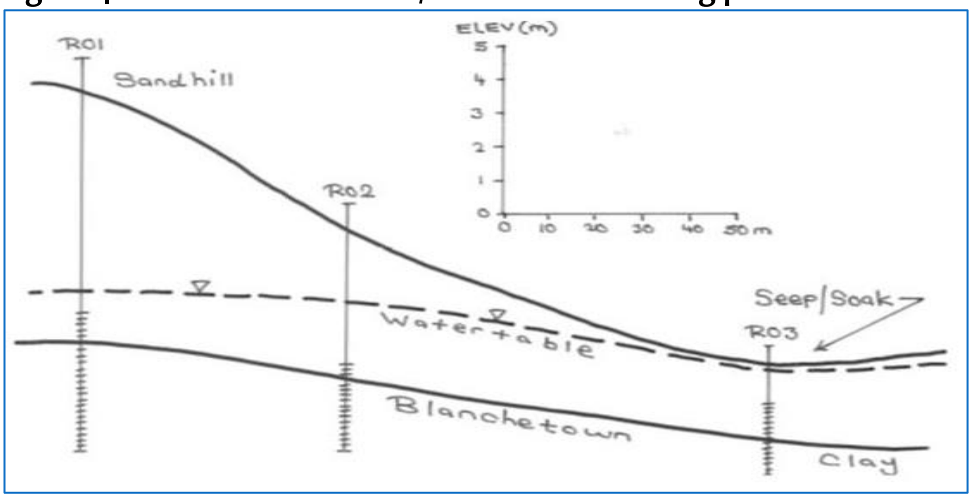


Photo 19. Rose/Thomas seep monitoring area showing piezometer locations

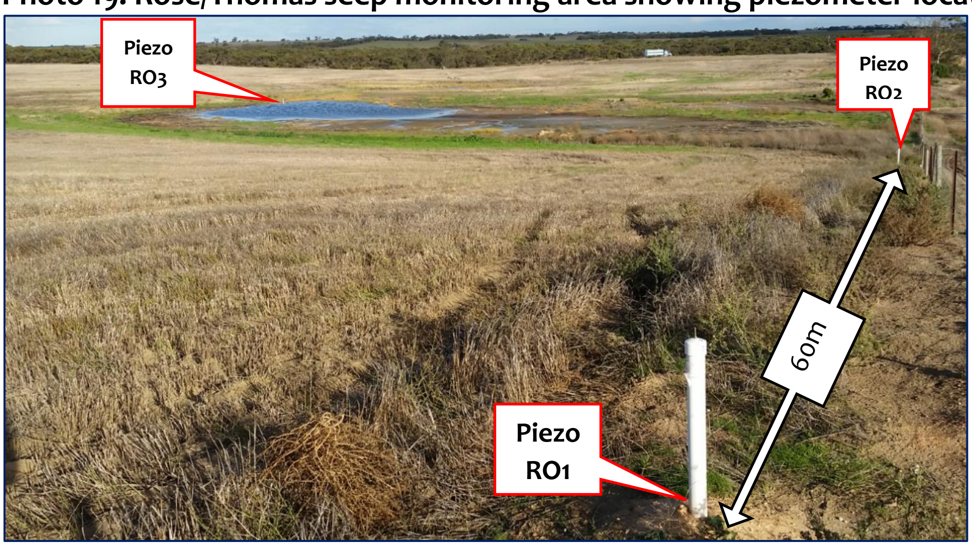
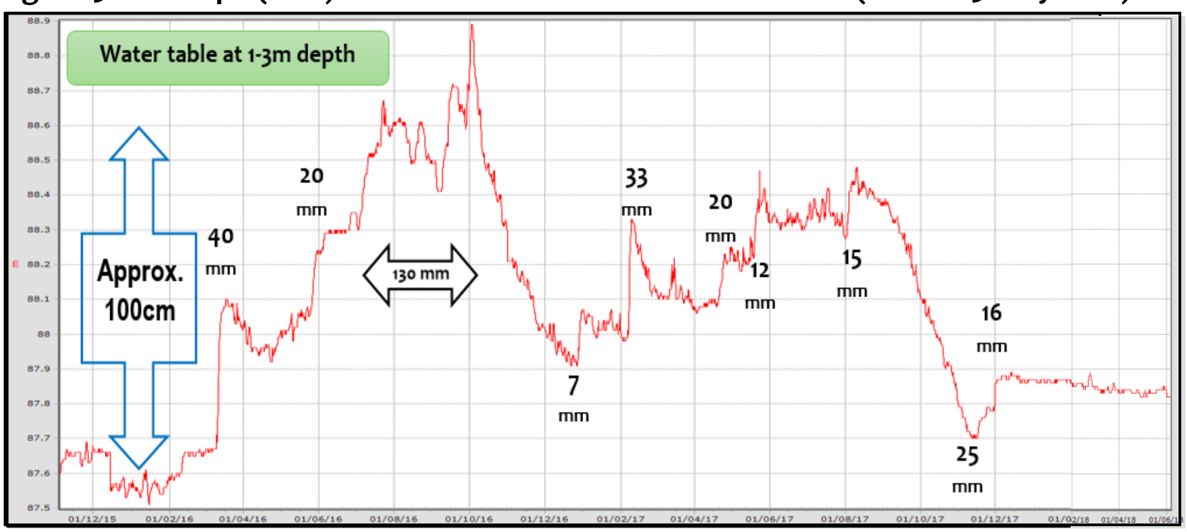


Figure 5 shows the rises in water table at the mid-slope piezometer location over a two and a half year period between Nov 2015 and May 2018. The water table at this site is below the crop root zone, so any rise is as a direct impact of rainfall that passed through the crop root zone and the sandy topsoil within the 60 m of sandhill slope above the piezometer. Any fall is most likely due to the discharge, evaporation or transpiration of the water below (particularly moving into the hotter summer period), or in some cases a bulge of water may be moving down the slope after a larger rainfall event.

The main findings from this catchment monitoring is that on these non-wetting sand hills that are continuously cropped with chemical summer weed control, relatively small rainfall events are contributing to significant recharge and water table rises. Figure 2 shows a 40 mm rainfall event raising the RO2 site water table by over 40 cm. Smaller event of 12 mm and 15 mm during the 2017 growing season lead to rises of 15-20 cm. Even a sudden 7 mm rainfall event in Dec 2016 caused a 10-15cm water table rise. This is from small amounts of recharge water across the 60 m sandy soil catchment above, laterally accumulating as the water travels down to the RO2 piezometer site.

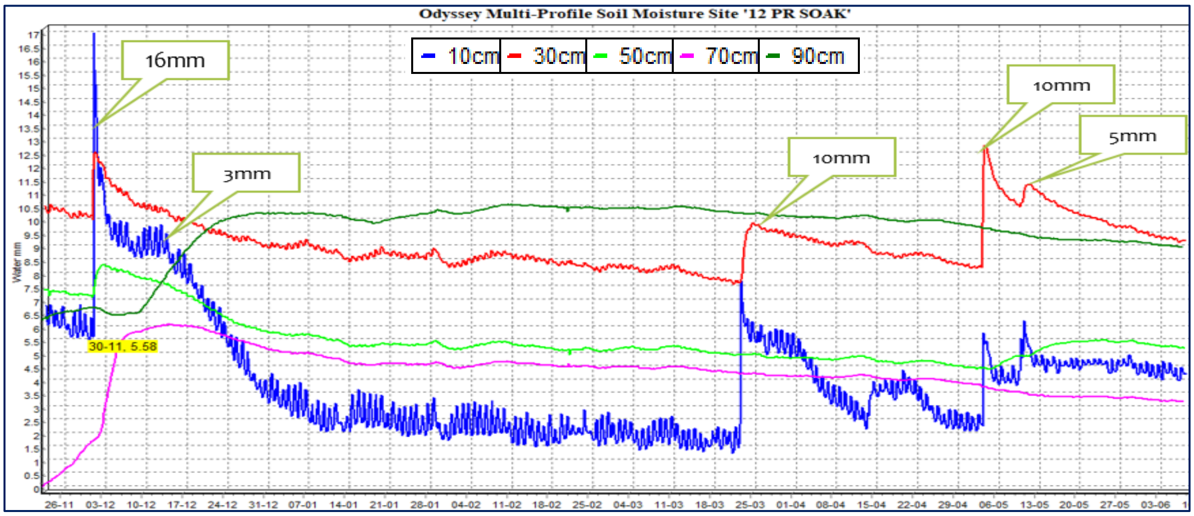
Figure 5. Midslope (RO2) water table rises after rainfall events (Nov 2015-May 2018)



Soil moisture probes have also been placed in strategic positions within catchments and constantly measure soil moisture at 5 soil depths down to 90cm. This allows for assessment of how various rainfall events, plant growth and evaporation may effect soil moisture within the root zone, as well as indication which rainfall events may cause water to pass through and contribute to recharge on different soils types.

The soil moisture results shown in Figure 6 (from a moisture probe placed on the top of the sandhill close to RO1 in Nov 2017) reveal the effects of a 16 mm rainfall on Nov 31st. The sharp spike in the blue line (10 cm sensor) can be seen to immediately pass through to the 30 cm sensor and then to the 50cm sensor over the following few days. 2 weeks after peaking both the 30 cm and 50 cm sensors have returned back to their original moisture level and kept falling (levels were still dropping after a 25 mm even earlier in Nov). There was then a dramatic moisture level rise at 70 cm, followed by a gradual rise in the 90 cm sensor about 1 week after the initial rainfall event. It is expected that this moisture movement would have continued in the same way further down the soil profile, forcing more moisture into the water table, to then begin a lateral accumulation of water flow through to the midslope (RO2) site, and then on to the discharge are (RO3). This is evidenced in Figure 5 where the 25 mm and 16 mm events have halted a rapid decline in the water table, raised it by 20 cm and then continued to maintain this level over the summer and autumn months (as water slowly drained through the catchment), despite very little other rainfall over this period.

Figure 6. Top of sandhill Moisture probe (near RO1)



It is also worth noting from Figure 6 that isolated 10 mm rainfall events did not always move moisture to the 50 cm depth of soil, and not to the 70 cm or 90 cm zones, when starting with a fairly dry soil profile. However, this can change when the soil profile is already wet, and these small events can penetrate deeper in these sandy soil profiles, as indicated by other soil moisture probe sites used in the project. On heavier loamy soil types a 10 mm rainfall event would rarely penetrate to the 30 cm sensor.

The Rose/Thomas main seep is mainly fed from the long sand hill to the north, as well as a smaller sand hill to the south, and so it is very understandable that this seep area has formed and has rapidly expanded, particularly after the very high rainfall periods of 2010-2011 (prior to which the whole area was cropped) and 2016, which has now seen this particular seep area expand to approximately 4 ha.

At other sites, such as at Bonds and Martins, the build-up of seep water often comes from a much larger catchment area of sand over clay soils, rather than at the base of a specific sand dune. In these cases, significant rainfall events now cause large amounts of water to accumulate in the upper sandy catchment areas, and move down across the low permeability layer of Blanchetown clay in high surges of water, discharging at the surface at various places in the landscape where clay is closer to the surface. This can mean that the time between a high rainfall period to when the discharge is seen in lower areas can take up to 6 months and can last for a very long time after. This has resulted in the rapid expansion in discharge zones, where it is now difficult to drive a tractor and establish a crop.

Figure 7 represents a cross section of the landscape at the Martin lower catchment site showing the piezometer positions across the slope in relation to the Blanchetown clay and perched water table. The red dotted line represents a surge of ground water moving down the slope after a significant rainfall event. Photo 20 shows the positions of these piezometers in the landscape with water from the Dec 2016 and April 2017 still discharging into the seep scald and cropping areas (Photos 21 & 22).

Figure 7. Martin lower catchment showing water table effects of moisture surge after rain (adapted from Hall, 2015).

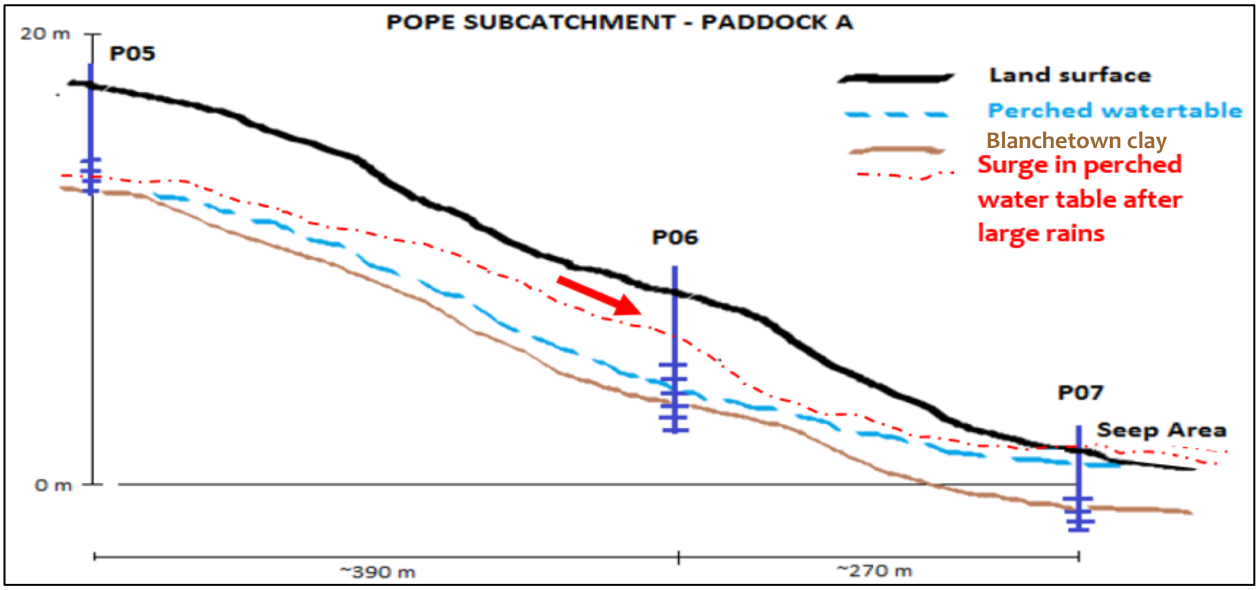


Photo 20 . Piezometer locations, main seep area, Aug 2017, with moisture discharging

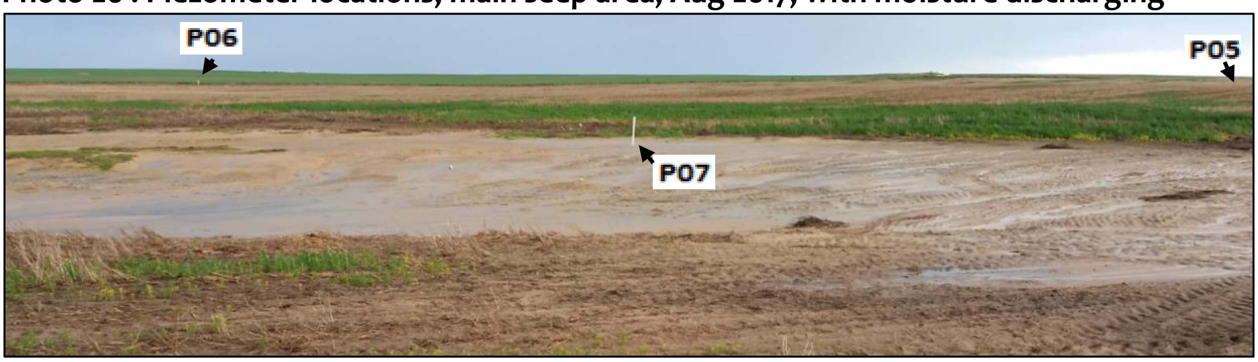


Photo 21. Expanding seep areas where crop sown, east & west of main seep, Aug 2017

The evidence that many major rainfall events are contributing to recharge and building up into large surges of water down the slopes becomes clear in Figures 8 to 12. Figure 8 shows the moisture probe sensor readings at 70 cm and 90 cm depth at the sandhill at the very top of the catchment. Each spike and sharp rise represents water passing past the crop root zone through to the layers beneath. Figure 9 shows rainfall data from a nearby rain gauge, showing four significant rainfall events over the 3 year period, ranging from 30 mm to 130 mm, each representing the beginning of surges in water table levels down the slope. Many other smaller events also contributed to small sharp moisture rises at depth but without resulting in the same water table impacts.

Figure 8. Top of rise, deep moisture sensor readings to assess possible recharge events

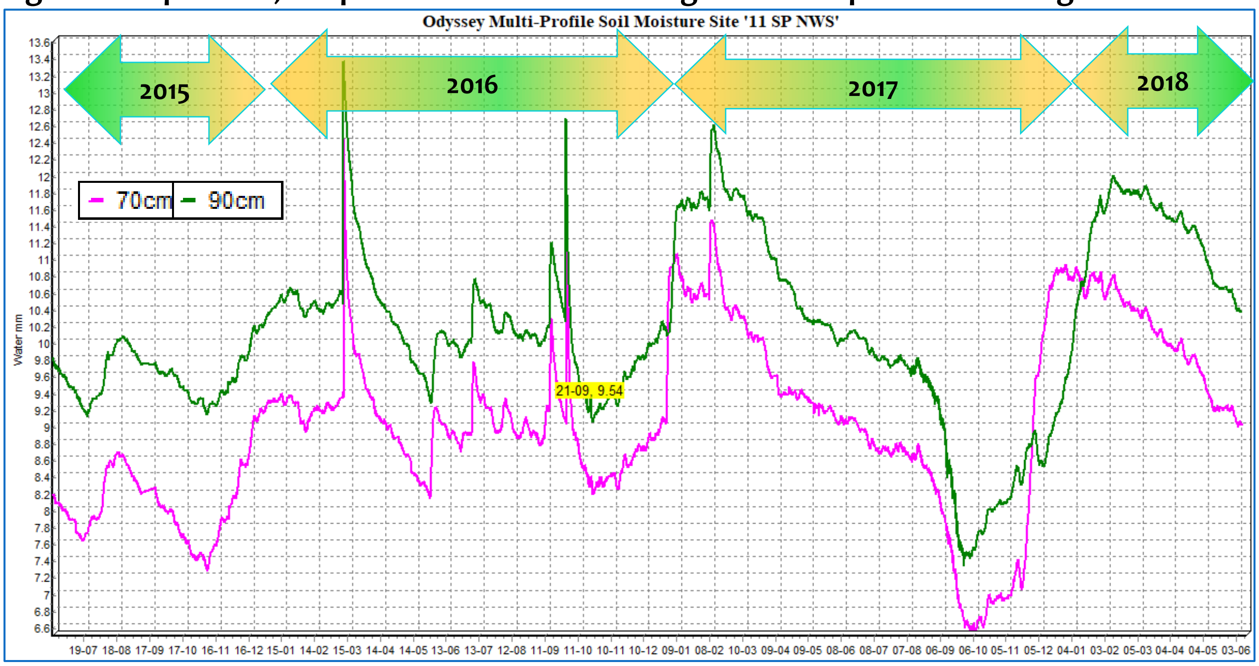


Figure 9. Corresponding rainfall readings to graph above, July 2015 - March 2018

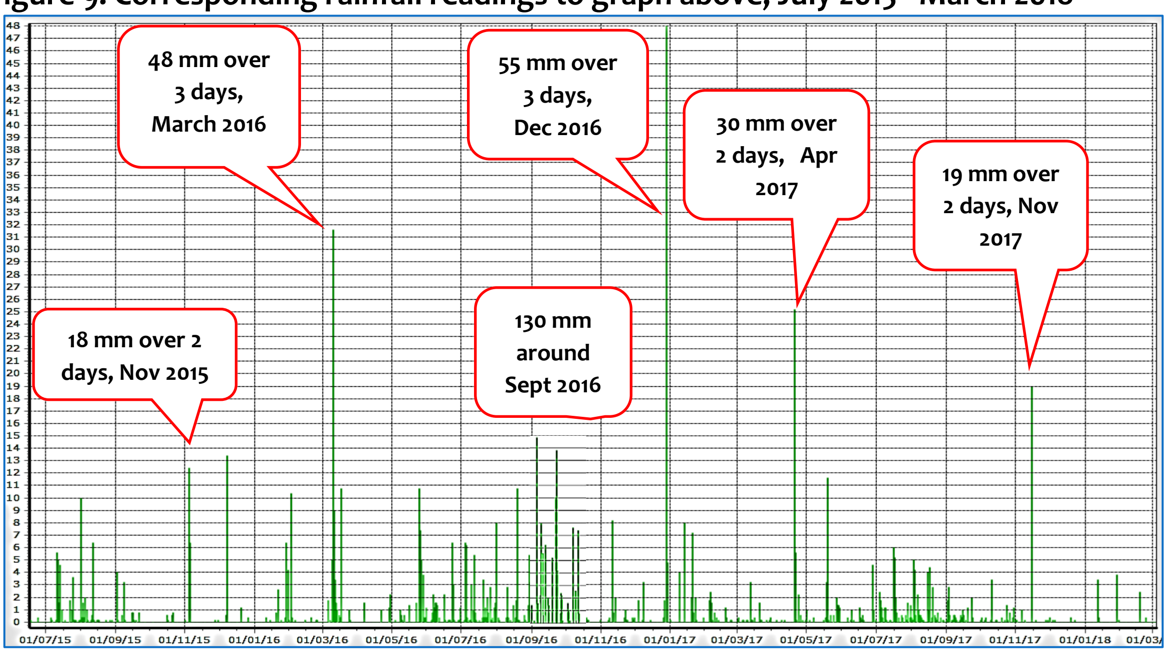


Figure 10. Piezometer 5 (Upper Midslope) showing water table rises, Nov 2016-Dec 2017

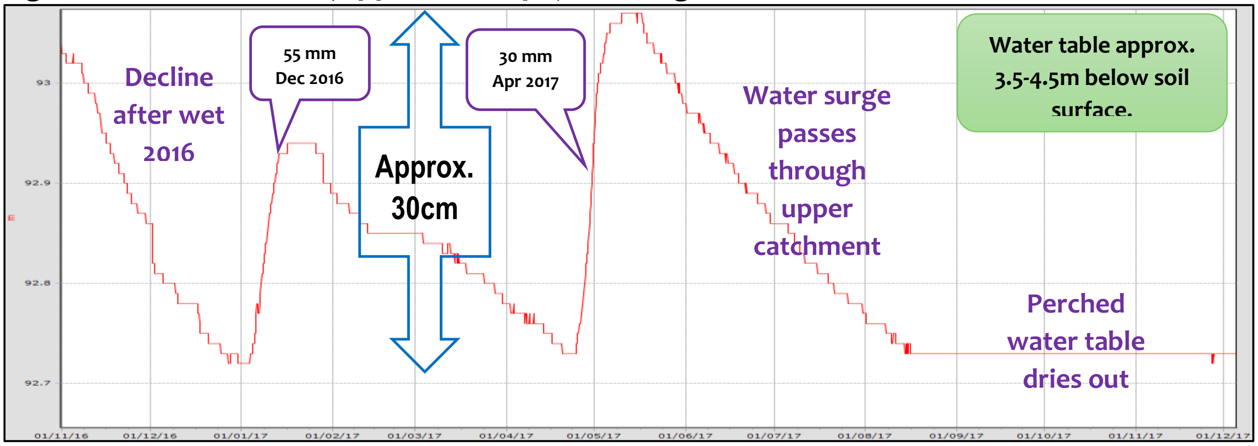


Figure 11. Piezometer 6, (Midslope) water table levels, eastern fence line, Nov 2016-Dec 2017

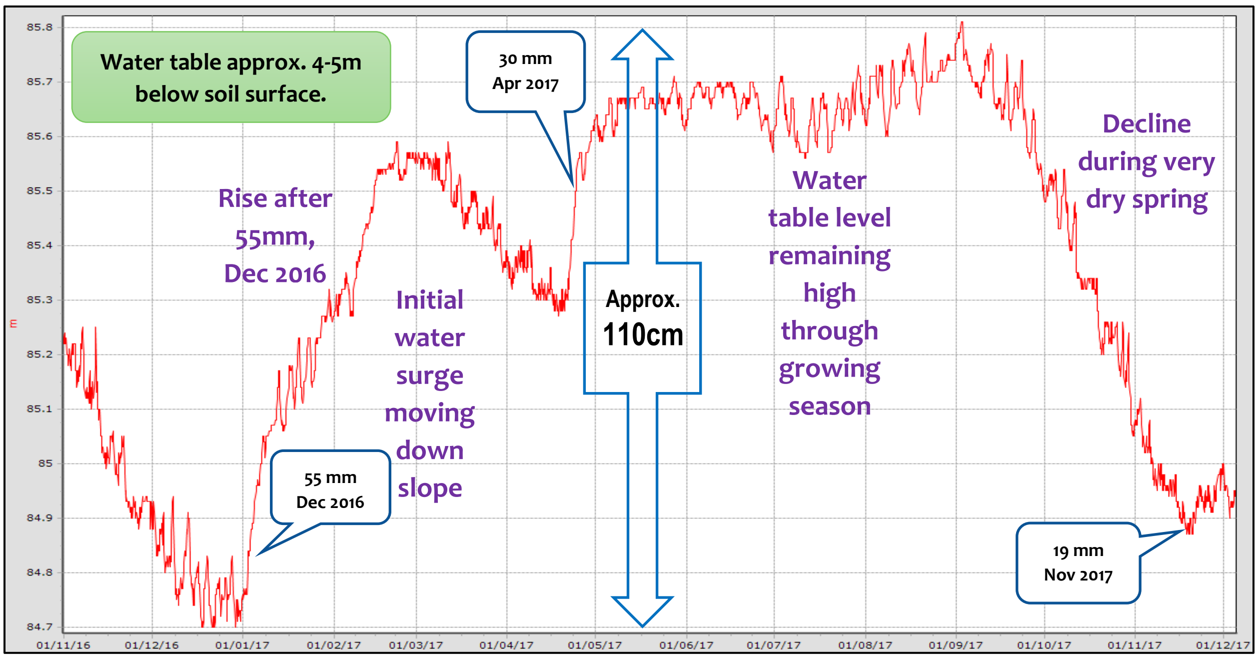
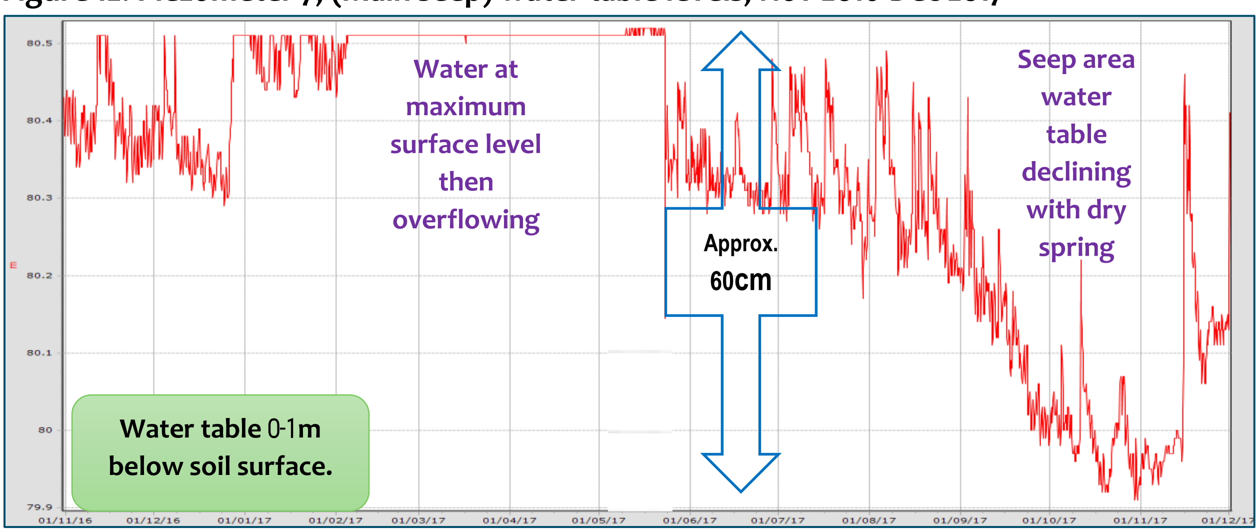


Figure 12. Piezometer 7, (Main seep) water table levels, Nov 2016-Dec 2017



The effects of these rainfall events from Nov 2016 – Dec 2017 are seen in the rise and falls in the water tables at the 3 piezometer sites (PO5, PO6 & PO7) running down the slope. Figure 10 shows the upper slope (PO5) water level rises quickly by 20-30 cm with each rainfall event of 30 mm or more, but the water passes though and the perched water table soon disappears until the next major rainfall event.

The piezometer further down the slope (PO6), which appears to be more in line with the natural catchment water flows, has risen by over 80cm after the 55 mm rainfall event (Dec 2016), and had only just started to fall (by 25 cm) when the next 30 mm rainfall event (Apr 2017) caused a further rise of 40cm. This was sustained despite very little growing season rainfall, until Sept 2017, suggesting that the water kept flowing through to this site from the catchment above for a 9 month period. This is evidenced by the water discharging around the rapidly growing seep areas in Photos 18-19, taken in Aug 2017.

The piezometer on the edge of the Seep area (PO7), showed the water table reached its maximum levels from Jan–May 2017 leading to surface overflow into lower areas of the paddock. Levels still remained very high with continual water discharge until Sept 2017, after which the water table began to subside.

Analysis of both the Rose /Thomas and Martin catchment results reveal that in some cases local sand dunes with deep non-wetting sands over clays can experience groundwater recharge, rising water tables and surface discharge in seep areas after as little as 12 mm rainfall. However, it is the larger rainfall events of 25-30 mm or more that tend to cause the greatest accumulation and surges in perched water tables at these sites, leading to a rapid increase in seep affected areas and the potential for permanent land degradation if no action is taken to strategically increase water use at these sites.

4 Managing Mallee Seeps

Managing mallee seeps is not an easy task. The fact that too much water is entering the farming system and that valuable land (often the farmers most productive land) is becoming degraded means that a land manager will have to make changes to address these issues. These are likely to require farmers to take different approaches with some inconveniences and disruptions to the previous ways of operating. However, the reality is that if nothing is done, permanent and expanding land degradation is likely to occur.

Low rainfall mallee farming is all about turning rainfall into dollars in the most efficient way while carefully managing the risks involved. While it should make sense to be able to better utilize excess moisture for profitable outcomes, this is not always easy to achieve within ones farming system or specific situation.

There are a number of management strategies that have been employed within this project that farmers could consider when working out the most practical options that suit their farming systems and situations. They are based within 4 main categories, including:

4.1 Changing to a higher water use farming system.

The most successful farming system for maximum utilization of all summer and winter rainfall is growing lucerne for either grazing or hay production. 19 ha of lucerne was sown above a seep area at Bonds property near Mannum in June 2015. This was monitored and compared for soil moisture use against land farmed to the farmer's continuous cropping notill farming system (Photo 22) using moisture probes with sensors to 90 cm depth.

Photo 22. No-till continuous cropping with summer weed control (left) vs lucerne (right).

The benefits of the perennial deep rooted lucerne in reducing the perched water table are clearly demonstrated at this site. Figure 13 shows sum of the probe sensor readings to estimate the changes in total soil moisture in the top 1 meter over time for each farming system. Once the lucerne slowly established over 2015, it brought the moisture level back to between 70 – 80 mm after each rainfall event. The consistent rainfall events from late May 2016 to Oct 2016 resulted in a period where soil moisture content was mostly between 90 - 110 mm, but then came back again to the 65-80 mm level through majority of 2017. Each time a significant rainfall fell, the lucerne quickly utilized it, no matter what time of year, resulting in no rainfall contributing to recharge. It is expected that the lucerne roots would have been penetrating and utilizing soil moisture to a far greater depth than measured within these probes, further enhancing this farming systems capacity to eliminate catchment recharge.

By contrast, the continuous cropping system quickly established and utilized soil water in the 2015 growing season (Figure 13). However, since Oct 2015, every summer rainfall has contributed to a consistent build-up of soil moisture. After the 30 mm rainfall event in 2016 the top 1 meter soil moisture level jumped to above 130 mm, so that at the time of seeding there was 60 mm difference in soil moisture between systems. While this is one of the reasons that summer weed control is encouraged in these low rainfall farming areas (to store valuable subsoil moisture for the crop), it also means that there is a far higher likelihood of recharge occurring, when larger rain events fall on soil profiles that are already close to field capacity.

Through the well above average 2016 growing season, the soil moisture in the top 1 meter on the cropping side was maintained at between 140-180 mm, over double the levels on the lucerne side. Even throughout the following dry season of 2017 the soil moisture levels general stayed between 130–160 mm (compared with 65-80 mm on the lucerne side). It is clear from 90 cm sensor that the crop roots are not penetrating to this depth to utilize moisture, meaning that this layer, as well as those layers below are likely to maintain high soil moisture levels close to field capacity. This means that every drop of water that leaves the rootzone will force a drop to push out the bottom and move laterally down the slope to the seep discharge areas. This is in stark contrast to the lucerne side in which each major rainfall is easily absorbed in the drier soil profile without causing recharge, and is used by the plants to quickly return soil moisture levels to their previous levels. This is clearly evident in the results shown in Figure 13.

This confirms that the lucerne plantation has definitely achieved its desired outcome of significantly reducing recharge since its establishment 2015. This is confirmed in the overall reduction in the mid-slope piezometer (BO2) water table of 90cm (Photo 23, Figure 14) which borders the lucerne area, despite the well above average 2016 rainfall year. This was the only piezometer that recorded a reduction in ground water levels during the very wet season of 2016 (which received around 200 mm higher than average rainfall across the district) out of all of the piezometers operating across the various sites.

Photo 23. Piezometer BO2 near bottom end of lucerne area, with main seep in background

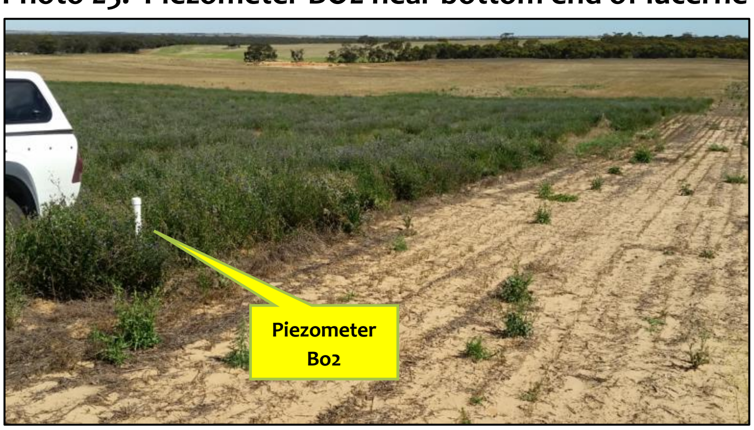


Figure 13. Long term summed moisture comparison of farming systems. July 2015-Dec 2017

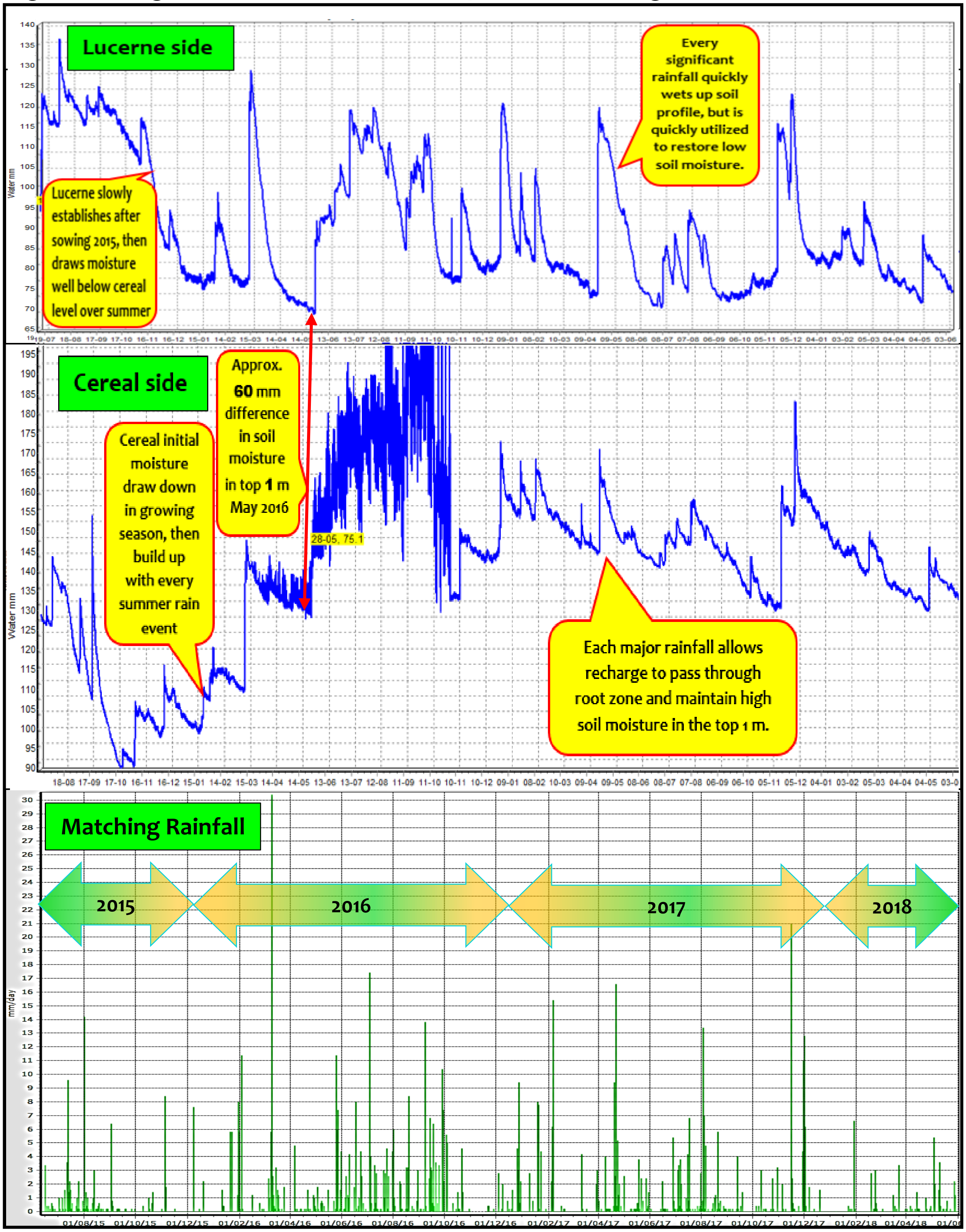
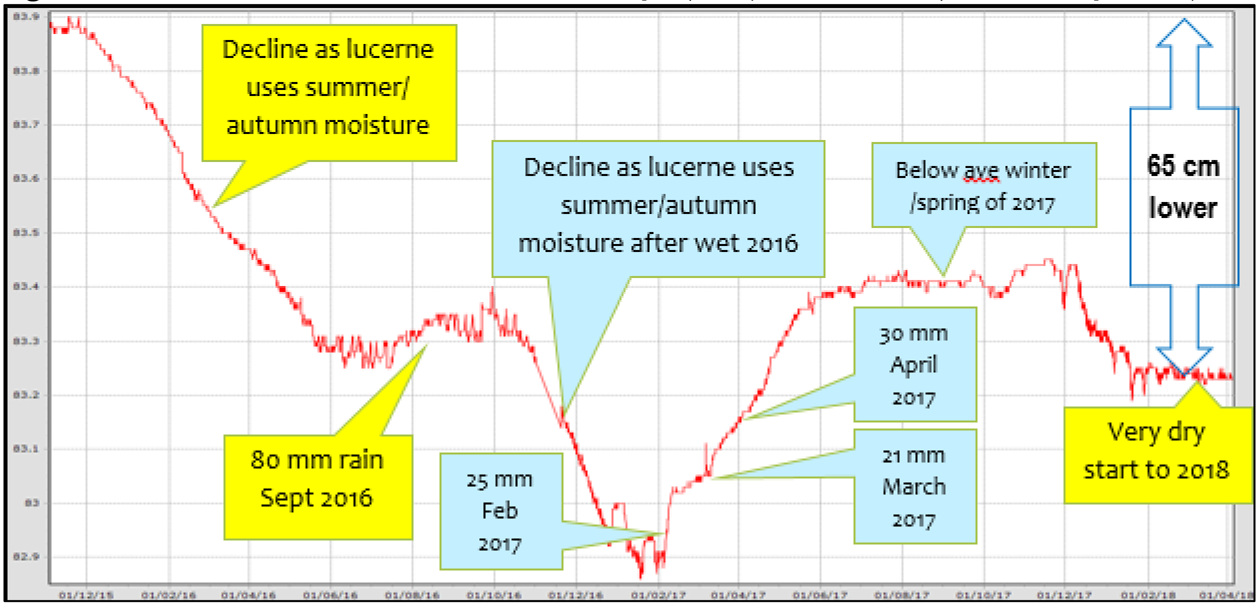


Figure 14. The effects of lucerne on the Mid-slope (BO2) water table (Nov 2015-Apr 2018)



Lucerne is a useful option for farmers, as it is relatively easy to establish and has multiple productive uses, such as grazing or quality hay production, allowing farmers without livestock to sell. However, sowing large areas to lucerne does not suit every farmers situation, as the hay market can be variable, and it can does take up valuable cropping land. The farmer must weigh up their options, taking a number of factors into account, such as:

- How will their lucerne production enterprise compare with their cropping gross margins, particularly if mainly established on less productive deep sandy ground,
- What is likely to be lost if no action is taken, in terms of permanent degradation to very productive farming land,
- Are there other strategic higher water use options available that better suit the farmer's situation?
- Are there agronomic options that can be employed on discharge areas to realise some production

At the monitoring site near Mannum, the Bonds established the lucerne and then were able to achieve up to 2 hay cuts per year, at an average yield of about 0.8 t/ha/cut, with a gross margin in the vicinity of $150/ha. Even though they are continuous cropping farmers with no livestock, and the area involved did disrupt their cropping operations to some extent, their attitude was that they were doing it for a reason, to protect their farm from further degradation, and that any returns they got back from it would be a bonus.

Overall, the lucerne establishment and hay cutting operation was less profitable in the short term, compared to cropping their land well, but they have been very encouraged by the changes the lucerne has brought to lowering the water table. They have, however, decided to change the location of some of their lucerne growing area, so that it will be over less area, but more strategically placed to maximize recharge interception.

4.2 Interception of lateral subsoil moisture flow above discharge areas, using strategic strips of lucerne, or tree planting.

Targeted lucerne strips.

While large scale planting of lucerne may not be practical for many farmers, the strategic establishment of lucerne strips to intercept and utilize excess groundwater before it discharges into seep areas is becoming more of a realistic option. Three of the four seep monitoring farmers have now sown lucerne strips in sandy ground just above seep discharge zones, similar to what is shown in Photo 24 at the Martins site.

One advantage of this strategy is that the lucerne should remain highly productive and not decline once the deep soil profile is dried, because there is always more moisture flowing in from the higher ground. While this project has clearly demonstrated the ability of lucerne to utilize soil moisture and lower localized water tables, there is little information available at present to determine how wide a strip of lucerne may need to be for a given local catchment size, to achieve the best results. It is also important to gain an understanding as to where the main flow of water is occurring within these perched water table landscape, so the lucerne can be used for maximum affect. These current sites should continue to be monitored over time to assess the success of these strategies.

Photo 24. Strategic lucerne strip to intercept lateral flow of subsoil moisture above seep

Strategic tree planting.

Tree planting above seep areas has historically been used in many areas to manage the problem of excess water flow through catchment areas. It is important to use the right species in the best areas and to use good planting and tree establishment techniques to maximize the success of these strategies. The Arbon site has highlighted many of these issues and monitoring equipment has now been established to assess the long term impacts of strategic perennial vegetation establishment.

In 2015, five rows of local mallee tree and shrub plants were established at the site along an existing fence line for 400 m, directly above a developing seep area, as seen in Figure 15. It has turned out that choosing to plant a long area with 5 tree rows has been important. Initially it was thought that the main flow of moisture sub water would be flowing from the elevated area of Seep 2, down through the blue hashed area which was very wet in the surface and dominated by ryegrass in the high rainfall year of 2016, then through the tree planting strip to the Seep 3 below. This appeared to be the most logical conclusion with visual assessment from the ground. However, when a piezometer was installed just above the tree line in Nov 2017, there was no evidence found of a perched water table above 7m depth, well below the water table found at the Piezometer 20 site, established on the top edge of Seep 3, below the tree line. It would appear that either:

- the water flowing down the expected pathway to the seep must be very intermittent following high rainfall events or above average years, and then drying out in the periods following, or
- the main subsoil water flow into the discharge area takes a different path, such as accumulating and flowing from the southern side of the sandhill above in a southeast direction (still within the tree line interception zone), or
- slightly south of this, with water flowing from the sand hill directly south to the heavier soil area (indicated by the blue/purple colours in the EM38 map, Figure 15) and then east into the discharge area.

This site will be monitored over the coming years as the trees mature, to assess their impact on reducing the rapidly growing seep area below. This also highlights the fact that visual observations of the surface landscape may not tell the whole story as to where key water flows are happening beneath, and therefore the best place to target moisture interception.

The other key outcome from this trial is the tree establishment method. The five row tree line was first sown in 2015 using a tree planter, but with no tree guards. While there was close to 350 trees planted, there were high number of losses due to damage by hares, rabbits and possibly kangaroos. There was also a distinct lack of water between sowing in June 2015 until March 2016, resulting in many plant deaths in this very sandy soil. Recent counts suggest there was only a 14% success rate. However, in 2017 the area was replanted by hand, creating a firm basin around each tree to enhance water collection when watered or after rain. A tree guard was placed around each tree which protected them from grazing (see Photo 25). They were hand watered in at establishment and also though the spring.

Despite having a very dry 2017, followed by almost no rain from Jan-Apr 2018, there has been a 76% survival rate across the 5 tree rows. Having multiple rows means that even where there are losses there are still numerous trees in line to possibly intercept lateral subsoil water movement. Ongoing pest animal and weed management is essential to ensure good survival of planted vegetation.

Understanding the salinity levels of the subsoil water is also important to make sure that suitable tree species are used. Other older tree planting sites are known to have been unsuccessful where local varieties have been planted above very saline water tables. However, in the early stages of seep formation the ground water is generally not saline.

Figure 15. EM38 map showing seep areas and likely water flow directions

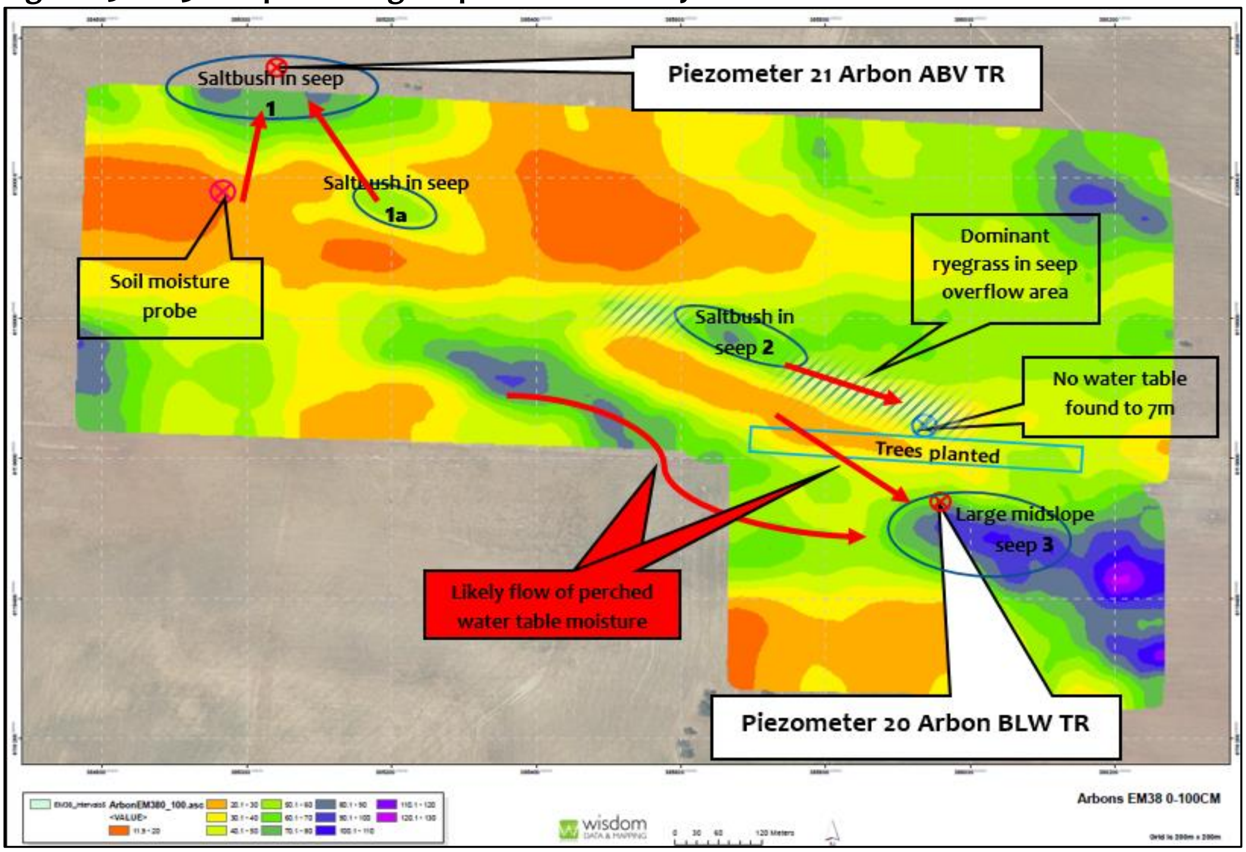


Photo 25. Tree planting rows above Seep area 3, taken from sandy rise end

4.3 Ameliorating sandy soils to retain and utilize more water.

This project has clearly shown that the major contributor of recharge water to the perched water tables and seep areas at these sites are the deep non-wetting sands. The main issues with sandy mallee soils are due to them being:

- low in fertility, organic matter, fine clays and structure, which greatly impedes their water holding capacity and productivity. While non-wetting sands can cause water to run across the surface, when it does soak in it is not well retained within the surface layers. Soil moisture probe results on these soils often see a sharp rise in each layers moisture level which will then return to its original level after only a few days, meaning the water has passed through the soil. Poor crop or pasture production means limited soil moisture utilization and transpiration.

- often highly compacted sand layers between 20-40 cm depth, as evident in Figure 16, which significantly restricts plant root growth (once penetration resistance approaches 3000 Kpa). It is often found that sands within and beneath this layer are high in moisture, even at the end of the growing season, as roots are not present to utilize the moisture and there is limited capillary rise or atmospheric loss of moisture at these depths. This means that excess water from each rainfall event does not have to travel very far before it may be impacting on recharge. This was very evident in a soil pit at the Martin site (Photo 26) where the majority of wheat roots were concentrated in the top 25cm, with very few penetrating into the wet soil beneath.

Figure 16. Mallee sand compaction, Loxton trial, 2015.

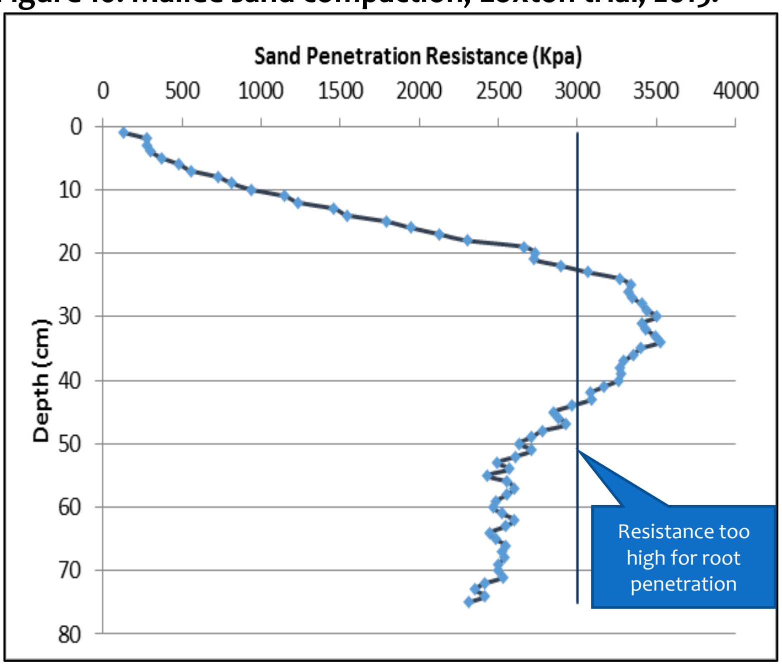


Photo 26. Most roots in top 30cm

(diagram supplied by CSIRO Sand Trial, Loxton 2015)

Many farmers seek to ameliorate or improve their sandy soils to better utilize their rainfall by increasing their productivity and profitability, and allowing this to deal with their seep issues. If this can be achieved it means minimal changes to their farming systems as well as increasing the productive capacity and value of their land.

One such trial was established in 2015 at the Pope/Martin site with the spading in of 6 and 9 t/ha chicken manure. A Spading machine acts like a large rotary hoe, mixing the soil to a depth of 30-40 cm (Photos 28 & 29). The chicken manure was delivered for approx. $30/t and spaded to a depth of 40cm. This was compared with spading alone, as well as control strips (Photo 27). The mixing in of this highly nutritious organic matter proved to have excellent results over the first 2 years of the trial. In 2017 there was severe mouse damage to the lupin crop, but the long term results are expected to be examined again in 2018.

Photo 27. Pope/Martin spading trial site 2015

Photo 28. Spading Machine

Photo 29. Rotating spading blades

Photo 30. Soil pits of Spaded only and Control Treatments, Pope/Martin trial 2015.

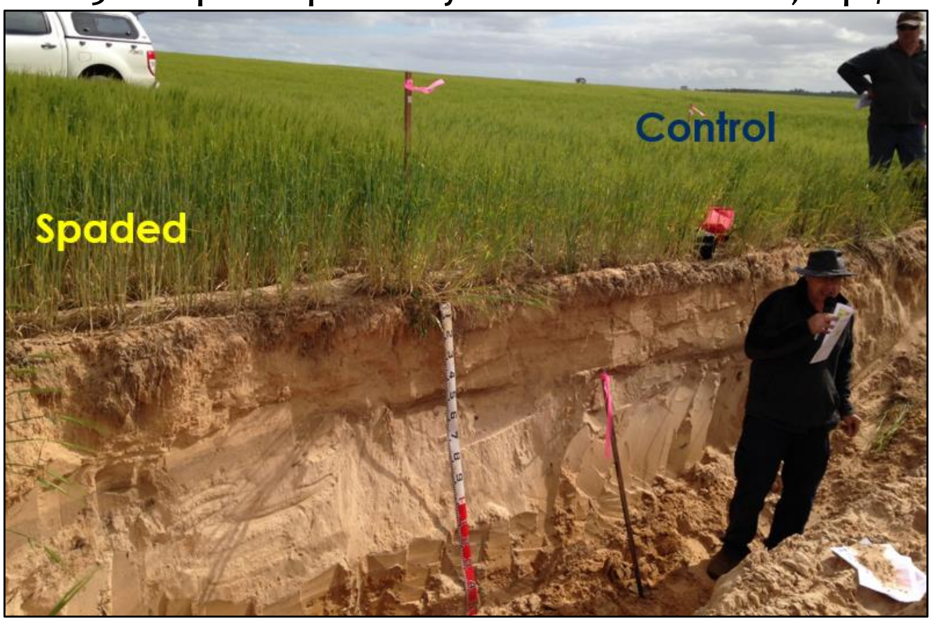


Photo 31. Spaded 9t/ha Chicken Manure showing superior crop and root growth, 2015

Photos 30 & 31 show clearly the crop effects obtained from improving the soil. In the control plot soil pit the roots were clearly all concentrated within the top 25-30 cm, with few roots penetrating deeper into the wet soil below. This was a clear indication of compaction at this depth. Where spading occurred the roots were evident all the way down to 1 meter, into the top of the subsoil clay. The visual difference between the crop growth in these pictures in phenomenal. The yield results over 2015 and 2016 (Table 1) show the 9 t/ha chicken manure spading treatments exceeding the control treatment yields by 1.8 and 1.9 t/ha respectively. While the up-front treatment costs are very high for both the manure and the spading contractor ($300-$400/ha), these treatments had already shown a very profitable gross margin. It would appear that the benefits of the higher chicken manure rate was coming through and be most beneficial in the longer term.

The importance of the increased nutrition and organic matter is revealed in the spading only treatment. While it was 0.7 t/ha better in the first season (by accessing deeper soil moisture), it was found to have exported far more soil nitrogen in the yield, depleting the soil reserves. Soil tests taken in June 2016 showed this treatment had around 27 kg/ha less N in the soil than the control, which would have been one of the reasons it yielded 0.1 t/ha lower that harvest. This clearly shows the importance of supplying extra nutrition with the spading, if longer term yield benefits are to be experienced. While spading can loosen compacted sand and allow roots to access deep soil moisture, these sands are still naturally extremely infertile and cannot reach yield potential without significantly higher nutrition. Spading alone causes mineralization of nutrients from soil biota in the first year which leads to yield increases in year 1, but deficiencies in subsequent years if not replenished.

The soil test results also showed that the N levels from the spaded chicken manure areas were similar to the control areas in June 2016 after exporting significantly higher N in the 2015 yields. The fact that the higher yields and proteins in 2016 led to 84 kg/ha more N exported from the 9t/ha Chicken Manure Spaded area than the control area, and 63kg/ha from the 6t/ha Chicken Manure Spaded area, show that the chicken manure continued to contribute significant amounts of mineralized N into soil throughout the growing season.

Table 1. Pope/Martin Chicken Manure Spading Trial, 2015 and 2016 harvest results

	2015 Ave Yield (t/ha)	2016 Ave Yield (t/ha)	2016 Ave Protein (%)	Ave N Export in Grain (kg/ha) 2016	Ave Treat. 2 Year GM over Control ($/ha)
Control West	1.5	2.3	8.2	85	
Spaded Only	2.2	2.2	7.9	77	$41
Sp Chicken Man 9t/ha	3.3	4.2	8.9	169	$416
Sp Chicken Man 6t/ha	3.3	3.7	8.7	148	$425
Control East	1.6	2.3	7.8	81	

The value of both breaking soil compaction and increasing soil organic matter in the top 40 cm by spading is clearly evident in Figures 17 & 18. The probe measuring soil moisture in the control treatment has seen many rainfall events quickly spike the moisture levels at 10cm and 30 cm depth, but then returns to its original position, while increases are quickly passed down to 50 cm, 70 cm and even 90 cm on occasion. There appears to be no draw down of moisture by crop roots at the end of the season below the 30 cm sensor (due to compaction). However, in the spaded chicken manure treatment, the 30 cm sensor practically mirrors the 10 cm sensor moisture, and stays moist for longer and used by crop roots. It is rare that any moisture passes to the 50 cm sensor. Instead there is a clear indication that the crops are exploring the deeper layers past 70cm mid-growing season. The 90 cm sensor in both treatments sits in the top of the clay layer, which explains its higher moisture levels.

Figure 17. Soil Moisture Probe, Control, 2015, poor water retention in root zone

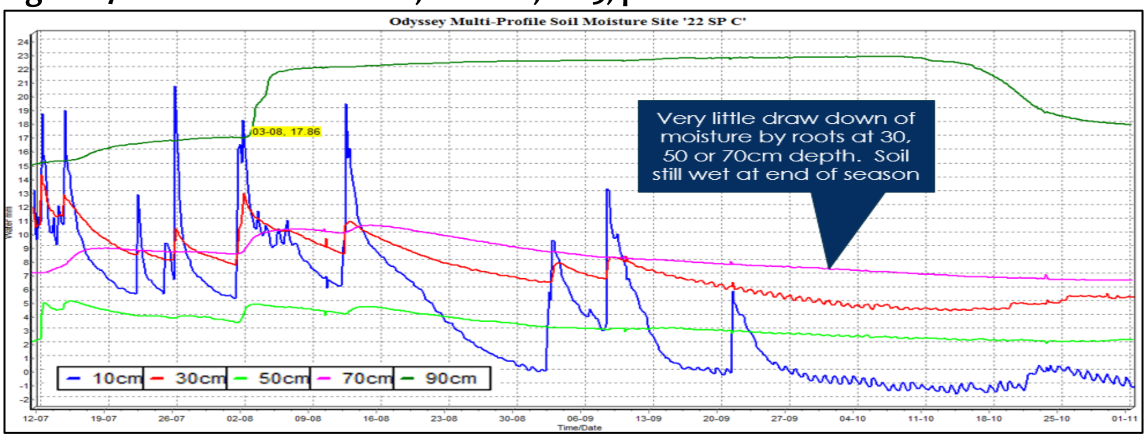
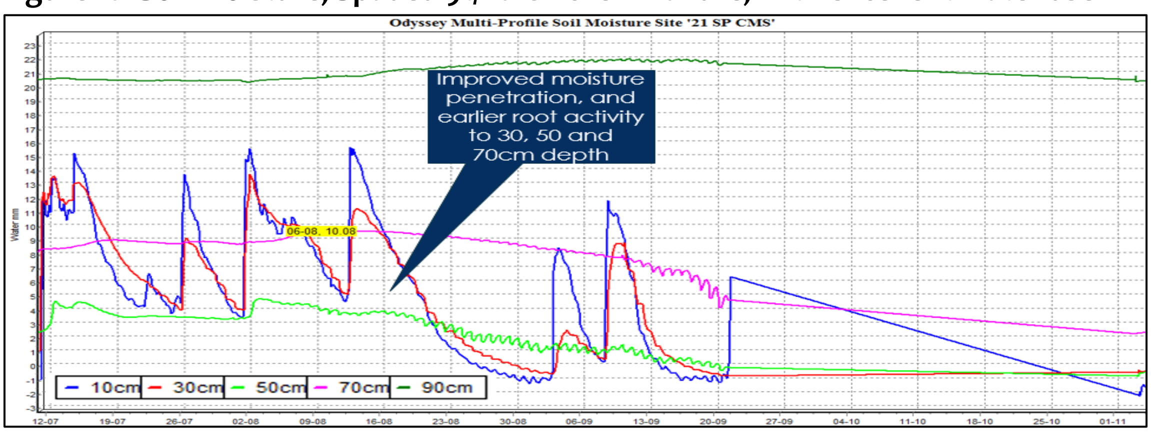


Figure 18. Soil Moisture, Spaded 9t/ha Chicken Manure, with excellent water use



While this technique helps to make far greater productive use of growing season rainfall, it also can have a positive influence on the utilization of summer rainfall. This is due to the fact that the crop roots can now explore and utilize all available moisture within the top 1 meter or so, meaning this zone will be dry when the first large summer rain falls, and able to hold this is storage until the next growing season. However, these sands still have fairly low water holding capacity, and so it is likely that large or repeated summer rainfall events may still contribute to recharge.

These soil improvements, along with the dramatically increased yields show that the amelioration of sands can have a dramatic impact on crop water utilization. If this treatment could be achieve across all the deeps sands in the catchment it is expected to lead to a dramatic reduction in seep development. Not all spading sites across the mallee have experienced the same production increases. It is a recommended management technique, but is presently under-utilized due to high upfront costs (despite shown to be profitable over 2 years), the poor accessibility of spading machines or contracting services. There is also the extra effort required by busy farmers to successfully implement this relatively new technology, often at a busy time of organizing there programs for the year. This may change in the future.

Ameliorating the deep non-wetting sands to retain more water and increase productivity is a very attractive option, as farmers don't have to take out valuable cropping land or change management programs to work around trees or lucerne patches. There are still some practical issues that need to be overcome to see a greater uptake of this technique.

4.4 Utilizing the excess water within the discharge areas.

Wherever bare scald areas are forming, maintenance of soil cover is vital to try and reduce capillary rise and evaporation that leads to the accumulation and concentration of salts at the soil surface. Once there is found to be salt crystals forming then it becomes increasingly difficult to rehabilitate that soil. In the past, salt and water tolerant grasses such as tall wheat grass and puccinellia have been used for both soil cover and grazing.

While it can be difficult to easily establish higher water use strategies on the deep non-wetting sands, there is also the option to better utilize the soil moisture where it collects and discharges, to achieve productive purposes. Monitoring sites have been established by planting fodder shrubs (saltbush or tagasaste originally in 2015, then saltbush replanted in 2017) and pastures (Messina in 2017) within the seep areas to utilize moisture, provide valuable grazing for livestock and provide soil cover to minimize evaporation and surface salt accumulation. This strategy is targeted in areas to utilize excess water before it becomes too saline.

Similar to the original tree planting, there were high losses of tagasaste and some saltbush due to hares and kangaroos. Replanting saltbush with tree guards has ensured survival rates of close to 90% (Photos 33-34). These areas have undergone steady grazing through the summer and autumn of 2017/18, and look to be a good prospect for the future. However, with some areas remaining inundated with water through 2017 following the wet 2016, it is evident that these plantations are not solving the problem by utilizing all the excess water. This may improve over time as the plants grow. It would appear that saltbush will not tolerate water inundation for long periods of time, and some losses have been experienced because of this.

Photo 32. Original saltbush establishment within seep areas

Photo 33. Some original tagasaste plants amongst saltbush in Seep 1 area at Arbons

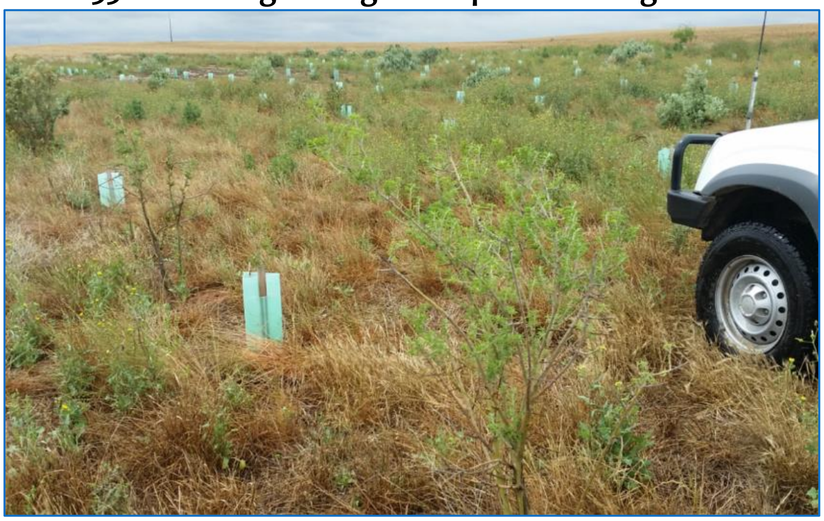


Photo 34. Re-establishment of some saltbush with tree guards.

In 2017, the lower seep area at Arbons was also sown to the new salt/waterlogging tolerant legume pasture variety of Messina, using very simple establishment technique of disc chaining the area (which was thick with ryegrass), then using a mouse bait layer to spread the seed (Photo 34). This proved to be reasonably successful in most areas, however the Messina struggled to establish in any of the bare scalded areas (as at other sites). As the season progressed it was evident that many seeds did eventually germinate once the conditions become more suitable for the plant, but this was fairly patchy.

While the Messina grew very well at both Arbons and Martins (Photo 35-37), providing excellent winter grazing potential, it is an annual plant and so dried back to a few sticks over summer, meaning it provided very little soil cover to protect this ground from evaporation which leads to salt accumulation in the surface layers (Photos 38). This is a time when evaporation is the greatest.

Photo 35. Messina growth amongst ryegrass at Seep 3 area, Arbons, Sept 2017

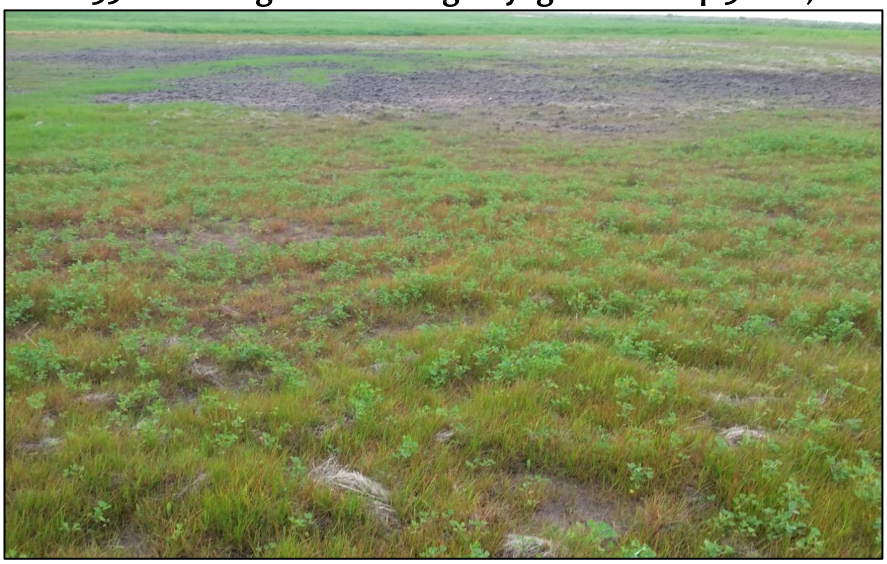


Photo 36. Messina establishing well just above the scalded seep areas at Martins, Sept 2017

Photo 37. Messina establishing amongst saltbush Seep 1, Sept 2017

Photo 38. Drying Messina resulting in limited soil cover

Using summer crops to soak up excess moisture and provide valuable cover over summer

To help combat the issue of saturated scald areas rapidly developing at the base of sandhills, the Bonds took the opportunistic step of sowing millet and sorghum into the specific cropping areas that were affected by waterlogging during the 2017 season. They did this after harvest and straight after the 25 mm Nov 2017 rainfall event as shown in Photos 39. It grew very well as can be seen in Photos 40 & 41, but only in the areas where moisture was accumulating. Anywhere the summer crops were sown further up the sandy rises, they quickly thinned out and died.

This has allowed the farmers to keep soil cover over the summer months, stopping the problem of evaporation leading to a concentration of salt at the surface. While it was hoped that the summer crops would help dry up these areas, it was found that the inflow of water from the upper catchment areas was still maintaining saturated soil layers beneath.

This strategy may become an important option for farmers, to help stop seep areas rapidly degrading after wet years by utilizing water where it appears, and providing soil cover over summer, without any major impact on their normal farming system operations. The Bonds reported that they were still able to spray over the millet with some summer sprays (for paddock summer weeds) and this caused very little damage. There were in, however, some areas of chemical use in the previous canola crop which did affect summer crop growth, which may require further investigation. While this strategy is not treating the source of the problem, it may prove to be a reasonable management solution by preventing land degradation without having to disrupt paddock operations by planting trees or lucerne.

When sowing into these areas where the summer crops had grown in 2018, the soil was still found to be very wet, and so while it is expected that the summer crops have helped use up moisture without compromising the following winter crop, it is not dealing with the real problem of excess water at its source.

Photo 39. Areas saturated during cropping season sown to millet after harvest

Photo 40. Millet and sorghum in March 2018 after low rainfall summer

Photo 41. Millet and sorghum in March 2018 after low rainfall summer

Photo 42. Cereal crop sown through summer crop residues in 2018

5 Conclusion

The Mallee Seeps Monitoring Project has provided a great deal of information and understanding on the development and management of seeps, by measuring actual catchment data about rainfall, soil and perched water tables at four monitoring sites over a period of 2015-2018. It has also monitored the development and results of farmer scale, practical and productive strategies that the landholders have employed in an attempt to manage and combat the increasing impacts of mallee seeps.

This project has identified the extent to which small rainfall events, as low as 10-12 mm, can lead to perched water table rises below non-wetting sandy rises, and that larger rainfall events (25-30 mm) can cause an accumulation of water to move within large catchment areas to discharge areas below, that can remain saturated for extended periods of time.

A number of strategies for managing seeps have been shown to be successful at increasing the utilization of soil moisture and reducing seep evaporation that leads to salinization, within four main categories, including:

- Changing to higher water use farming systems, such as growing lucerne for hay production and grazing,
- Intercepting the lateral movement of water table moisture before it reaches discharge areas, such as growing strategically placed lucerne strips and tree lines,
- Ameliorating sandy soils to hold and utilize more soil moisture before it contributes to recharge and perched water tables, such as the spading of chicken manure,
- The productive utilization of excess soil moisture within the saturated seep areas as they form, such as through salt bush plantings and tolerant pasture species establishment, as well as use of targeted summer cropping.

There are many issues that require further monitoring and investigation, such as:

- The areas required for intercept plantings (or lucerne or trees) to adequately protect land from the catchment landscapes above,
- The most practical and least expensive methods available to adequately ameliorate sandy soil profiles for extended periods of time,
- The development of NDVI imagery analysis and technology to equip farmer and managers with the early detection of potential seep development and proactive prevention and management,
- The best ways to establish soil cover on baring scalded seep areas,
- The herbicide tolerance levels of summer crops to both crop herbicide residues and summer weed herbicides.

This project has been very successful in raising the awareness of seep issues, both within the SA and Victorian mallee and further afield, as well as contributing to successful funding applications for ongoing seep management projects and programs that will continue this vital work for our farming communities.

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Each of the above mentioned reports can be found on the Natural Resources SA Murray Darling-Basin Website at http://www.naturalresources.sa.gov.au/samurraydarlingbasin/land-and-farming/soils/soils-resources