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Water for a Healthy Country

Evaluation of the impacts of deep open drains in the Narembeen area, wheatbelt of Western Australia

INTRODUCTION

Over one million hectares of the wheatbelt of Western Australia (WA) are affected by secondary salinisation and this area is expected to increase to over 3 million hectares if current trends continue. Deep open drains, as an engineering solution to dryland salinity, have been promoted over the past few decades. Despite problems such as variability in drainage response and the relatively flat landscapes in the wheatbelt, deep drains are increasingly seen as a viable option in this region.

Main drain near Narembeen town.

Drains now exist in almost every catchment in the wheatbelt. The total length of these drains has been estimated to be greater than 12 000 km, but they are generally scattered, and without extensive regional linkages. Most of the drains have been constructed with limited planning, design, and construction guidelines, and usually with little analysis or understanding of downstream effects. Few formal evaluations of their effectiveness exist. This absence of scientific understanding of drain design and performance, coupled with their widespread adoption and lack of regional planning and design, created a polarised social context for salinity engineering in Western Australia.

As a result of the existence of more than 70 km of drain in the Narembeen area, CSIRO, with support from GRDC and assistance by the Department of Agriculture, took the opportunity to work with farmers to evaluate the impacts of deep open drains in the Wakeman subcatchment (32° 5.3´S, 118° 23.8´E) some 280 km east of Perth.

In this subcatchment, a large proportion of the valley floor soils had been cleared by the 1930s, with subsequent clearing on the hillsides taking place as recently as the 1970s. Salinity first developed in the 1960s after a period of high rainfall and is predominately within the valley floor. The deep palaeodrainage sediments (up to 80 m) are covered by a 1–3-m alluvial blanket of sands and grey-brown and yellow-brown clays. Multi-directional porous material lenses exist within the top 1 to 3 m of the soil. Ferricrete and silcrete, in isolated units, occur between 2 and 7 m depth. The predominant land use in this subcatchment is wheat and barley in rotation with pastures and lupins. Some farmers also grow canola and other legume crops.

Several sites were selected and instrumented in the Wakeman subcatchment (Figure 1) to evaluate the impact of deep open drains on shallow and deep groundwater levels, soil root zone salinity, crop productivity and quality and quantity of flow.
A brief summary of the results are presented here.

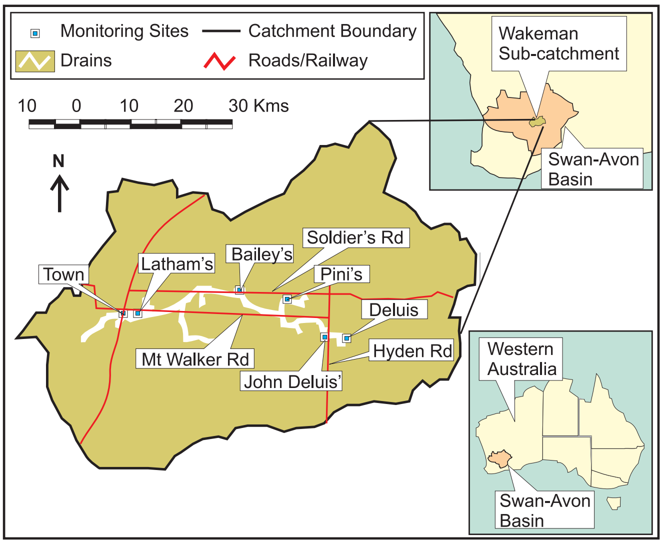

Figure 1. Map showing the location of study area and various experimental sites in the Wakeman subcatchment of the Avon basin of Western Australia.

1. IMPACT OF DEEP OPEN DRAINS ON GROUNDWATER LEVELS

Six sites were selected in the Wakeman subcatchment (Figure 1) to evaluate the impact of deep open drains on shallow and deep groundwater levels. Transects of shallow and deep piezometers were installed and equipped with capacitance probes. Both shallow and deep groundwater level data were collected from all selected sites throughout the four year monitoring period. Analyses of the groundwater level data from one site where the drain was installed a week after monitoring commenced (Baileys), and at others where yearly comparisons were made with non drained areas (Table 1), suggested that the effect of drains on the groundwater levels was significant (Figure 2). It was particularly significant if the initial water levels were well above the drain bed level, permeable materials were encountered, and drain depth was adequate (>2 m). Visual observations and evidence derived from this study area suggested that if the drain depth cut through more permeable, macropore-dominated siliceous and ferruginous hardpans, which exist 2–3 m from the soil surface, its efficiency exceeded that predicted by simple drainage theory based on bulk soil texture. The effect of drains often extended to distances away (>200 or 300 m) from the drain (Table 1). Immediately following construction, drains had a high discharge rate until a new hydrologic equilibrium was reached. After equilibrium, flow

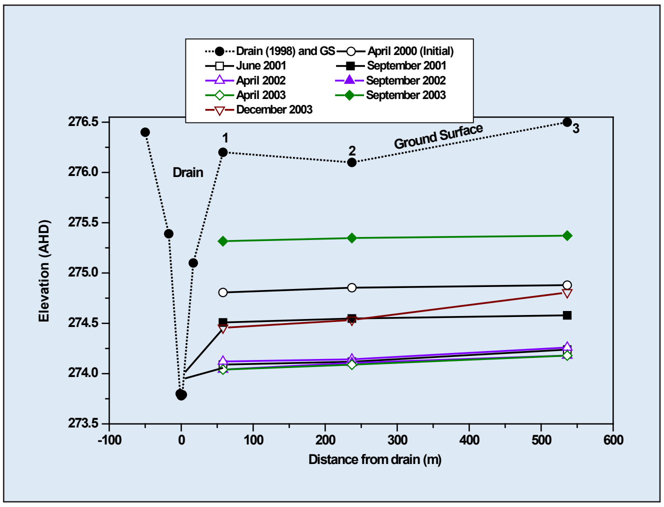

Figure 2. Temporal variation in the shallow water levels at Latham site (September 2003 indicates effect of a wet season and that in these years drains have to remove this water to be effective – see Table 1).

Piezometer	Period	Periodic decline (mm)	Periodic rate of decline (mm/day)	Total decline (mm)	Rate of decline (mm/day)	Overall average decline (mm/day)
			Latham site (drained area)			
1	22/8/03–25/9/03	560	16.00	880	10.14	8.55
	26/9/03–9/12/03	320	4.27			
2	29/8/03–30/9/03	445	13.44	865	9.72	
	1/10/03–9/12/03	420	6.00			
3	9/9/03–4/11/03	455	8.03	580	5.78	
	5/11/03–9/12/03	125	3.53			
			Bevan Thomas site (undrained area)			
1	26/8/03–25/9/03	185	6.00	375	4.27	4.42
	26/9/03–9/12/03	190	2.53			
2	23/8/03–27/9/03	280	7.71	510	5.43	
	28/9/03–9/12/03	230	3.15			
3	30/9/03–9/12/03	190	2.67	190	2.67	
4	28/8/03–30/9/03	270	7.98	540	5.92	
	1/10/03–9/12/03	270	3.87			
5	30/9/03–9/12/03	270	3.80	270	3.80	

Table 1. Rate and overall decline in the shallow water levels in a drained (Latham) and undrained (Bevan Thomas) catchment

largely comprised regional groundwater discharge and was supplemented by quick responses driven by rainfall recharge. Comparison between the hydrology of the drained and undrained areas in the Wakeman subcatchment showed that, in the valley floors of the drained areas, the water levels fluctuated mainly between 1.5 and 2.5 m of the soil surface during most of the year. In the valley floors of the undrained areas, they fluctuated between 0 and 1 m of the soil surface.

2. IMPACT OF DEEP OPEN DRAINS ON SOIL ROOT ZONE SALINITY

This part of the study tried to assess the impacts of deep open drains on root zone salinity in the drained areas of the sub-catchment. Four sites were selected, two in the drained areas (Latham and Pini) and two in areas that were proposed to be drained (Bailey and John Deluise). Binannual soil sampling, up to 1.6 m depth at several distances away from the drain (up to 200 m), was carried out for four years to assess changes in root zone salinity and pH profiles.

Analyses of the soil salinity data suggest that pre-drain soil surface layer salinity was high during summer, especially at Bailey (Figure 3) and John Deluise sites. After drain construction at Bailey site, soil root zone salinity decreased substantially (Figure 4). The greatest impact was observed on soil surface layer salinity. It remained low (below thresholds for barley and wheat) at the drained sites throuhout the four year monitoring period. To find out where within the soil profile the soil salinity and pH improved over time, the average of all salinity and pH values from all sites at each depth segment was calculated for the sampling events of June 2000 and April 2002 and plotted (June 2000 was the time when soil sampling for salinity was carried out for the first time; April 2002 was selected because it was a dry year and the effects of evaporation on the soil surface layer salinity build up will be apparent). Over time the soil surface salinity reduced, but it remained relatively unchanged in the deeper parts of the soil profile (Figure 5). Soil pH may have increased slightly in the soil surface and deeper layers and remained unchanged in middle layers of the soil profile. This change may or may not be attributed to drainage (Figure 6). The areal influence of deep open drains on soil root zone salinity could only be assessed up to 200 m away from the drain at Pini and John Deluise sites and 100 m at Bailey and Latham sites. The analyses of data suggest that the drains had an effect and reduced the soil surface layer salinity at least up to these distances away from the drain. The results imply that deep open drains improve soil surface layer salinity due to leaching of the salts following watertable reductions and significant rainfall events. These results and our conclusions bely the difficulty of assessing the impact of the drains on soil salinity levels. Strong effects of seasonality, cultvation, and sampling cannot be neglected from the analysis. However low groundwater levels and improved crop productivity at drained sites support the assessment that the soil surface layer salinity improved over time.

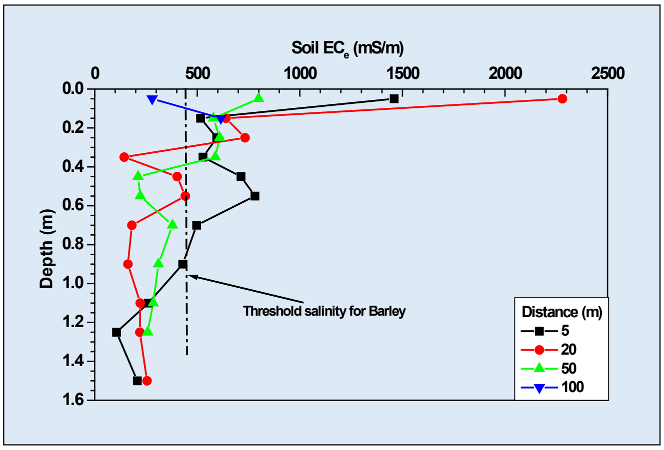

Figure 3. Soil root zone salinity in the transect A of Bailey site in October 2000.

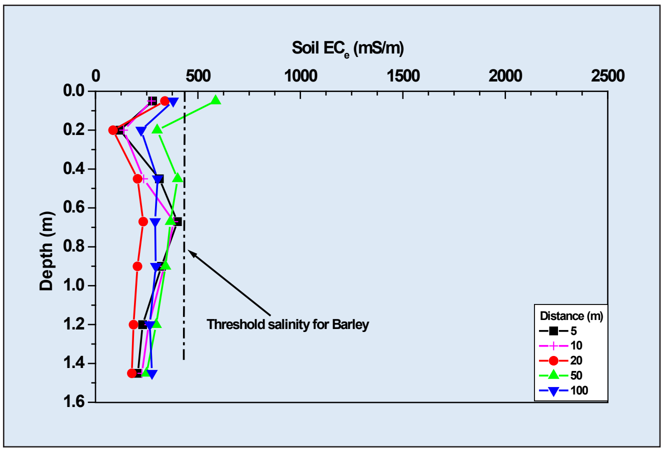

Figure 4. Soil root zone salinity in the transect A of Bailey site in April 2002.

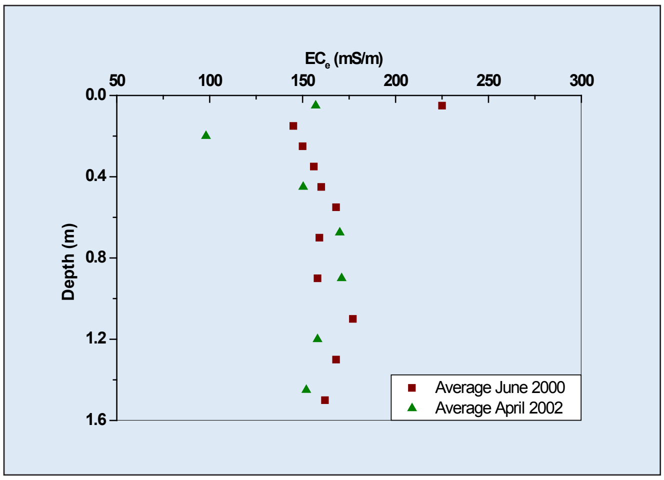

Figure 5. Average of all observed ECe values from all sites at each depth segment in June 2000 and April 2002.

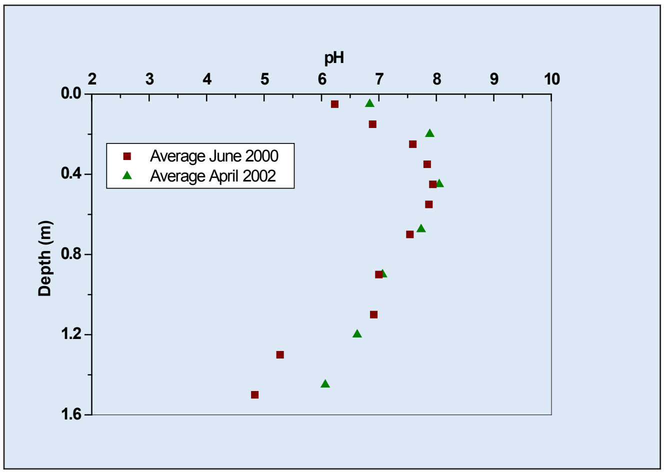

Figure 6. Average of all observed pH values from all sites at each depth segment in June 2000 and April 2002.

3. QUALITY AND QUANTITY OF DISCHARGE FROM DEEP OPEN DRAINS

To evaluate the quantity and quality of discharge from deep open drains, five sites (Town, Latham, Pini, Bailey, and Deluise) were selected (Figure 1). At each site, automatic water samplers were installed and water samples were collected continuously for four years (2000 to 2003). The samples were analysed for EC and pH regularly and for major ions and heavy metals occasionally. To monitor the drain discharge rate, UDIs (Ultra Doppler Instrument) were installed in the drains at all selected sites and drain discharge data collected (200 - 2003). Shallow and deep groundwater salinity and pH were also monitored biannually in the piezometers installed at various distances away from the drain at each site.

Drain discharge rate varied depending upon the length of drain upstream of the location of its measurement, season and age of the drain. Generally flow rate in the drains was very significant during first two years of monitoring (Figure 7). Outflow rate varied between 5-15 ML/day (sub-catchment outlet). The outflow rate decreased substantially towards the end of year 2002 due to dry weather conditions but increased again following winter 2003 due to above average rainfall. The salt outflow rate was directly related to water outflow rate. The increased water outflow rate following significant rainfall events caused increased outflow of salts. During 2000 and 2001, the salt outflow rate varied between 300 and 800 tons/day (Figure 7). It decreased substantially towards the end of 2002. During and immediately after winter 2003 rains, the salt outflow rate increased again. By the end of 2003, it was close to about 100 tons/day due to decreased flow rate.

The salinity and pH of the drain water varied between an EC of 4000 and 10,000 mS/m and a pH of 2 (summer) and 4 (winter). This pattern in pH and EC mirrors that of the aquifer. No significant change in the drain water salinity and pH (Figure 8), were observed during the four years monitoring period that was not the result of a rainfall induced variability in surface inflow and groundwater discharge. With the current level of drainage in the sub-catchments dominated by groundwater derived baseflow, a significant decrease in the drain water salinity (which may have been expected by some analysts) has not occurred to date. The concentration of heavy metals in the drain water varied among various sites. Most of the heavy metals were significant but the concentration of iron (Fe), aluminium (Al) (Figure 9) and manganese (Mn) were very high. Excessive levels of manganese, aluminium and iron may potenially be harmful for the downstream flora and fauna. Further studies have been initiated to evaluate their impacts on downstream flora and fauna.

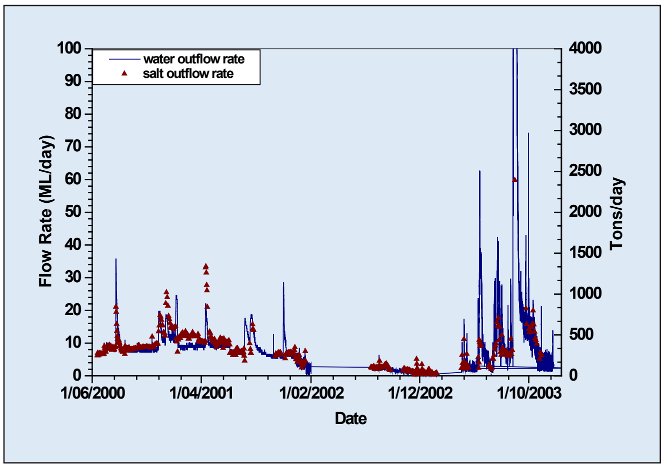

Figure 7. Temporal flow and salt outflow rate from the drain at Narembeen town site. Peak flow was over 100 ML/day in 2003.

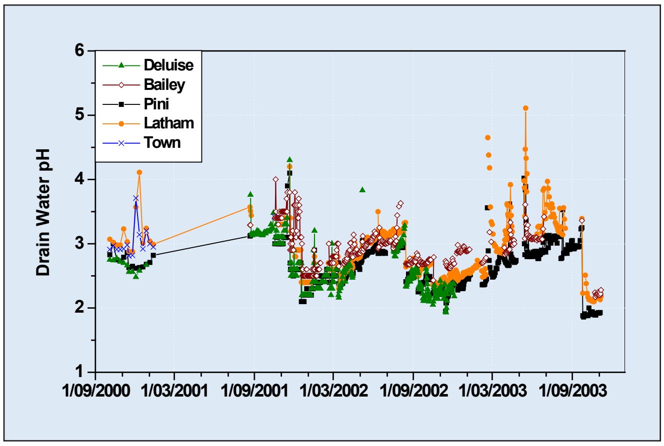

Figure 8. Temporal variation in the pH of water in various drains.

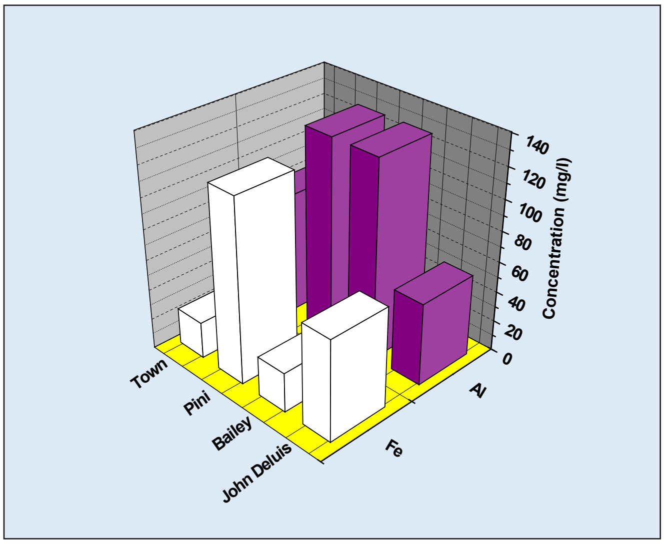

Figure 9. Concentration of Fe and Al in the drain water at various sites.

4. EVALUATION OF THE CROP PRODUCTIVITY IN THE DRAINED AREAS.

The effect of the deep open drains on crop production and soil salinity was investigated using a combination of remote sensing and ground-based measurements. The aim of this work was to identify areas of previously salinised land which have been reclaimed for agricultural production by drainage. Yield response via direct measurements was also quantified at selected sites. Yields could then be compared to root zone salinity measured via soil sampling.

A temporal sequence of Landsat-TM images were examined to determine areas which were previously unproductive due to salinity and are now cropped adjacent to the drains. Images dates were chosen to target the peak growing season (Aug-Sep) when green biomass is at its maximum. These images were processed to develop a technique to identify areas that were previously salt-affected and unproductive which have been returned to production due to drainage. Images were processed to classify basic landcover types and salt-affected areas.

Analyses of the temporal sequence of Landsat-TM images (no ground truthing was carried out prior to the drain) show that there are areas adjacent to the drain now cropped were previously classified as samphire and other salt tolerant vegetation dominated (Figure 10). However there are also areas that are still not cropped - pink and light green - and are classified as poor or salt affected. This supported anecdotal evidence from the farmer who stated that some of these areas had not produced a harvestable crop in 20 years. Areas adjacent to the main drain which have been "reclaimed" appear to be producing more mid-season biomass than those adjacent

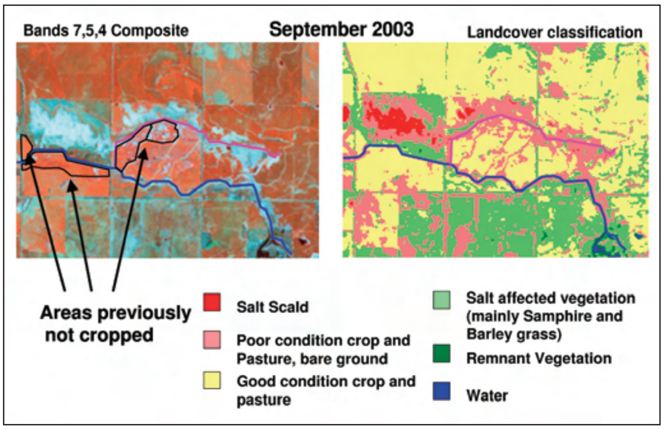

Figure 10. Composite image and landcover classification for the Bailey site in 2003 showing crops in areas not previously cropped.

to the more recently constructed lateral. Other sites in the catchment show similar increases in cropped area close to the drain.

Crop production at four sites was also measured directly using 100 m strip harvests at intervals perpendicular to the drain. A soil and groundwater monitoring scheme was used to examine the impacts of drains on soil root zone salinity and groundwater levels. It was found that land previously considered as unproductive due to high root zone salinity prior to the drain was cropped in subsequent years following drain construction with varying success, depending on the depth and construction technique of the drain. The strip harvest data indicates that a reasonable Barley crop was grown in 2003 close to the drain at the Bailey site (Figure 11) where prior to the drain the groundwater levels were very shallow (0.5 m) and soil surface layer salinity was very high. Other sites also show crops growing adjacent to the drains in 2003.

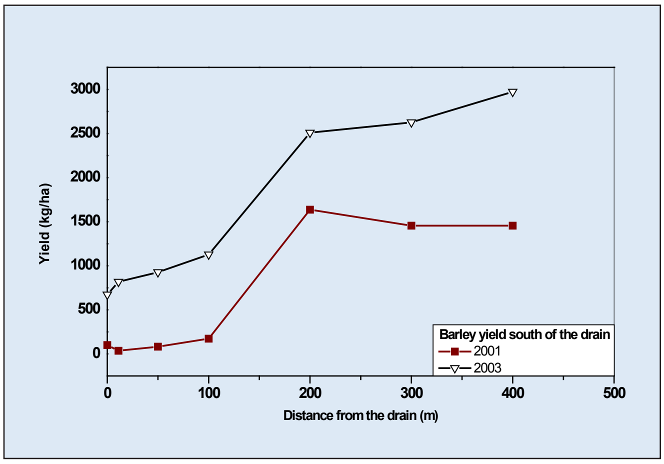

Figure 11. Barley crop productivity near the drain at Bailey site.

5. GUIDELINES FOR DRAINAGE DESIGN AND EFFECTIVENESS

To frame meaningful drainage guidelines, five sites were selected and instrumented in the drained and future drained areas of the Wakeman sub-catchment. The instrumentation included weather stations and rain gauges (to monitor and measure the metrological parameters), shallow and deep piezometers (to assess the effects on shallow and deep groundwater levels), automatic drain water samplers (to monitor drain water quality), and UDIs (to monitor drain flow rates). The sampling included biannual soil sampling for soil salinity, soil moisture and soil pH, crop productivity measurements, drain cross sections, and silt and erosion measurements. The following guidelines were framed based on the detailed analyses of all of the above data collected over four years from the selected sites.

Guideline 1. In order to be most effective, a deep open drain should be more than 2 m deep and/or be constructed in permeable materials.

Analyses of the last four years data showed that drain depth was one of the most critical determinants of its efficiency. The drain depths at Town, Latham, Pini, Bailey and Deluise sites ranged between 2 and 3 m. These drains had probably lateral impacts on watertables up to 200 - 300 m away from the drain and the water levels were below 1.5 m of the soil surface during most of the post construction monitoring period. At John Deluise site, the drain depth ranged between 1 and 1.5 m. This drain was not effective beyond about 10 m away from the drain.

Guideline 2. In order to be most effective, a deep open drain should cut through the confining ferricrete layer which exists in many landscapes of the wheatbelt.

The effectiveness of deep (>2 m) open drains is well above that predicted by the conventional drainage theory based on physical properties of the bulk soil. The most likely reasons for their increased effectiveness are the existence of lenses of porous material in the top 3 m (Figure 12) and a ferricrete layer of varying density and thickness between 1.5 and 3 m depth of the soil profile. Analyses of the data collected from Wakeman sub-catchment, visual observations and experience from drainage trials at other locations in the wheatbelt suggest that the drains that cut through this layer yield increased groundwater contributions from unconfined aquifers beneath and within, the hardpan.

Figure 12. Dye test showing preferential flow paths in the soil profile at John Deluise site in the Wakeman sub-catchment.

Guideline 3. A leveed groundwater drain (defined here as a deep open drain that is designed to entrain only groundwater flow) requires less construction and maintenance costs and is therefore more effective than an open drain (defined here as a drain that entertains both surface water and groundwater).

Measurements of cross sections of both leveed groundwater and open drains over the last four years show that open drains silted more than leveed groundwater drains due to transportation of sediments by surface runoff into the open drains. Unless de-silted regularly they become less effective. More erosion of the side slopes and banks were observed in the open drains due to generation of unstable flow velocities especially during the winter period. To make them as effective as leveed groundwater drains, they need more frequent maintenance. This entails greater initial construction costs (adequate capacity, proper side slopes, gradients, proper placement of spoil banks, and adequate capacity of culverts and bridges) than for leveed groundwater drains for whom although the same design requirements apply but for much less flow rates and volumes.

Guideline 4. A drain should have enough capacity to handle the designed flows.

Both types of drains exist in the Wakeman sub-catchment. Open drains lack capacity to handle surface run-off from significant rainfall events and overflow causing silting and erosion. Since an open drain entrains both surface water and groundwater, its designed flow rate (discharge) should be based on a flood/rainfall event of 5-10 year recurrence interval. A drain constructed based on this designed flow rate is likely to incur higher construction costs unless adjacent stream is also considered as conveyor of surface runoff. However the likelihood of silting of the drain will be much higher. Therefore it is preferable to construct a leveed groundwater drain. A leveed groundwater drain is usually designed on the basis of groundwater flow only. Experience from the Narembeen drains, and other in the eastern wheatbelt suggests a design flow of 50 kL/km/day should be considered.

Guideline 5. A properly designed drain should have adequate side slopes based on the type of soil and drain.

The side slopes of a drain depend on the type of soil. It is recommended to determine the natural angle of rest of the soil before selecting the slopes of a drain. It is also advantageous to observe the side slopes of old ditches in the area for an estimate of the stable side slopes. In the Wakeman sub-catchment, most of the drains were constructed as trapezoidal sections, with relatively steeper than recommended side slopes due to limitation of the digging equipment. The cross sections of these drains measured over a period of four years showed that the side slopes became flatter (0.25:1 to 0.45:1) over time for the groundwater drains. In the case of an open drain at Latham site, the designed side slopes were (0.25:1). During the course of four years, the side slopes on both sides of the drain became flatter in different proportions. On the side of the stream (open to surface runoff from adjacent stream) the side slope changed to about (0.70:1) and on other side (closed side due to spoil bank) it successively changed to (0.5:1). Therefore in leveed groundwater drains, the minimum side slope in this type of soil should be 0.5:1 and for open drain the minimum side slope should be 1:1.

Guideline 6. The longitudinal gradient of a drain should be such that it reduces the risk of silting, erosion and unstable velocities.

The gradient of a drain is generally governed by the topography of the landscape where it will be constructed. Usually field drains have a longitudinal gradient of 0.1 to 0.3%. In the relatively flat areas, the gradient is determined by the minimum drainage depth requirements in the upstream section of the drain and by the lowest level of discharge at the outlet. If sufficient gradient is available then it should be determined by the maximum permissible velocity. In the drains at Latham and Town site, the gradient was measured annually for the last four years and was averaged around 0.3%. Similar gradients were observed for drains at other sites in the Wakeman sub-catchment.

Guideline 7. The velocity of flow in a drain should always be between the maximum and minimum permissible.

The maximum permissible velocity (nonerodible velocity) is the greatest mean velocity which will not cause erosion of the drain. It is usually highly variable and can best be estimated through experience and judgement. If designed inadequately, the maximum velocity is usually an issue in open drains where rainfall events of significant magnitude and intensity produce runoff and cause higher than maximum permissible velocities. This causes excessive erosion and silting in various reaches of the drain. This behaviour was observed in open drains of the Wakeman sub-catchment. Whereas in the case of groundwater drains, the maximum velocity was not an issue and this was mainly the reason for less erosion and silting of drain body. Therefore for a better control of the velocity of flow in the drain, it is preferable to construct leveed groundwater drains at least at the farm scale level. Controlled velocities in these drains will help reduce erosion and silting and enhance their efficiency. The velocity which will avoid sedimentation depends on the diameter of the bed material to be transported. The average flow velocity in drainage channels should always be more than minimum permissible velocity to avoid silting.

Guideline 8. The spoil banks should be properly shaped with reverse gradient and placed 3-4 m away from the drain edge.

Embankments or spoil banks of the drains should be placed in such a way that they prevent the entry of surface water. To avoid scouring of these embankments back into the drain, they should be properly shaped and placed at 3-4 m away from the drain edge. This 3-4 m strip should have reverse gradient so that the rain falling directly over this strip does not make its way into the drain. The spoil bank top should also have gradient away from the drain to avoid its erosion and washing into the drain. A drain designed and constructed following the above guidelines is likely to be more effective and will require less maintenance costs.

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