Government of **Western Australia**
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Drain batter erosion trial at Wubin

Salinity and land use impacts series
Report No. SLUI 50
May 2009

Looking after all our water needs

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NM Cox & SF Tetlow

Department of Water

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Cover photo: Wubin step batter drain
Photographer: Nick M Cox

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Summary

The accumulation of sediment within the channel floors of deep open groundwater drains reduces their effective operating depth. To maintain drainage depth requires de-silting every 3–10 years which can add a significant cost to the operation of the drainage scheme.

Groundwater drains are often in silty and sodic soils that are predisposed to erosion. As the majority of groundwater drains are enclosed within levee banks, most of the sediment originates from the erosion of the drain batters by raindrop impact and runoff from the adjacent drain structure itself. Altering the shape of the channel or the width of the berms are possibly ways of either constructing more stable batters or reducing the runoff over them.

To investigate the effect of erosion and sedimentation on channel shape and berm, a trial drain was constructed at Wubin, in the Western Australian Wheatbelt. Three drain cross sections with different batter slopes and shapes were trialled. A 4-m wide berm was left on one side of the channel, and a 1-m berm on the other. The degradation of the drain structure was recorded over a 12-month period with precision surveys and reference point photographs.

A flatter uniform batter slope (1:1 vertical to horizontal) and wider berms were more effective in reducing batter erosion and sediment accumulation rates than steeper (1:0.5) or stepped batters and narrow berms. However, because the evaluation period was short and rainfall below average, there was little difference between some of the drain shapes and a longer period with more rainfall is needed to affirm the results.

The cost of construction and maintenance of the three drain designs was compared. The cross sectional area of the 1:1 batter drain was 50% greater than that of the standard 1:0.5 batter drain and cost more to construct. Although it was the most stable design with reduced sedimentation, the additional cost of constructing the 1:1 batter channel was more than the cost of digging the smaller channel and de-silting it more frequently over a 20-year period.

1 Introduction

There appear to be few places in the world where deep open trenches are used to drain groundwater and to lower watertables as is being done in the Wheatbelt of Western Australia (Chandler & Coles 2003). The many publications on groundwater drainage commonly refer to agricultural drainage schemes as consisting of buried porous conduits, tiles and pipes. These buried schemes share none of the erosion and sedimentation problems that plague open drains.

With limited references available, drainage practitioners attempt to apply design criteria for surface water conveyance channels to groundwater drains. The main difference is that surface channels are designed to convey water at bank full capacity (Schwab et al. 1981), while groundwater drains rarely convey sufficient flow to cover their channel floor.

While capacity and flow velocity dictate the design of surface drains, achieving maximum depth with minimum excavation usually underpins groundwater drainage. In achieving these conditions, questions arise about how steep channel batters can be before they erode excessively or collapse when exposed to raindrop impact and runoff from the adjacent berms and levee banks.

A standard groundwater drain cross section appears to have evolved over the last 20 years across the Wheatbelt with a compromise between the limitations of the excavation equipment and channel stability. These drains are usually 2-m deep with a 0.9–1.2 m floor width and a 1:0.5 uniform batter slope. This cross section is not varied in response to different soil conditions unless it is apparent at the time of excavation that the batters will collapse.

The channels stay bare and subject to erosion because soils (clayey, saline) are usually unsuitable for establishing vegetation. Under low-flow conditions eroded soil accumulates on the channel floor, reducing the effective depth of the drains and so their ability to lower the watertable. This raises the question: ‘Would different drain batter slopes or shapes remain more stable over time and reduce the rate of sedimentation of the channels?’

This question was addressed by the Engineering Evaluation Initiative (EEI), established in 2002 to evaluate various engineering solutions to Wheatbelt salinity. As part of its program on specific farm-scale engineering options, the drain batter trial site was constructed in August 2006 near Wubin, Western Australia to evaluate the channel stability of three different drain cross sections. The drains were excavated as part of the Mongers 55 drainage scheme implemented by the Yarra Yarra Catchment Management Group (YYCMG 2008).

The objectives of this trial were:

- Compare the rates of erosion and sedimentation of three drain batter designs.
- Assess batter erosion beneath 4-m and 1-m wide berms.
- Evaluate the cost of construction and maintenance of the three drain designs.

2 Site description

2.1 Location

The drain batter trial site is in the north-eastern Wheatbelt, approximately 240 km NE of Perth, Western Australia. The site is on the property of Russell and Janette McPherson (Victoria Location 4441, at 476 100 mE, 6 692 064 mN) in the Shire of Dalwallinu, 41 km NNE of Dalwallinu and 24 km NE of Wubin (Fig. 1, CD Appendix 2.0).

The site is very flat, with gradients less than 0.1% (1:1000) and severely affected by dryland salinity. All evidence of the previous agricultural land use has disappeared and the land is colonised by halophytes (Fig. 2).

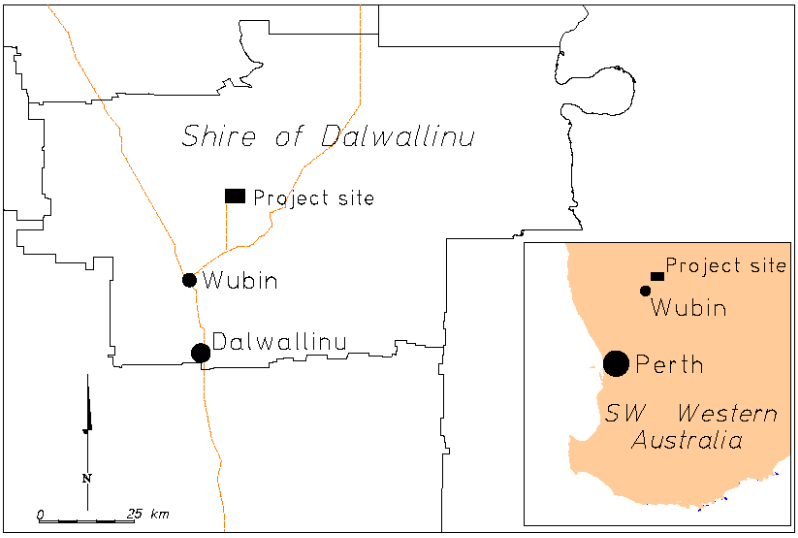

Figure 1 Location of project site

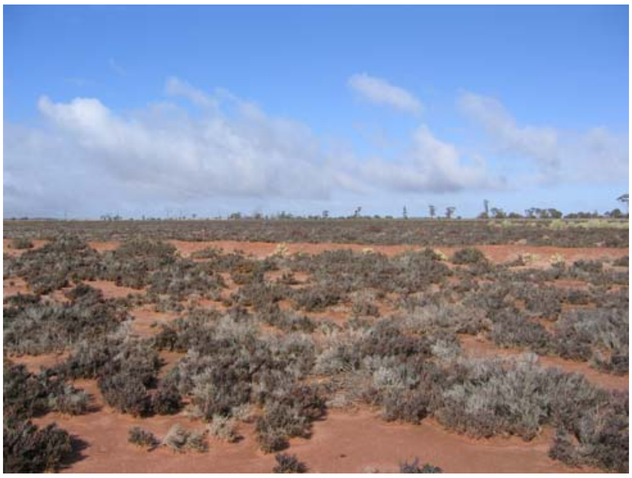

Figure 2 The Wubin drain batter trial site

2.2 Climate

The climate is Mediterranean–type with cool wet winters and hot dry summers. Approximately 60% of rain falls in the cooler months between May and August. The long-term average annual rainfalls for Wubin and Dalwallinu are 318 and 357 mm respectively (Bureau of Meteorology 2008). Both towns recorded below-average rainfalls in 2006 and 2007.

A pluvio rain gauge (station number 508045) at the trial site recorded daily rainfall over the 16-months July 2006 to October 2007, totalling 189.2 mm (Appendix CD 2.2). Apart from the summer months November 06–February 07, monthly rainfall at the site was well below the Wubin average (Fig. 3).

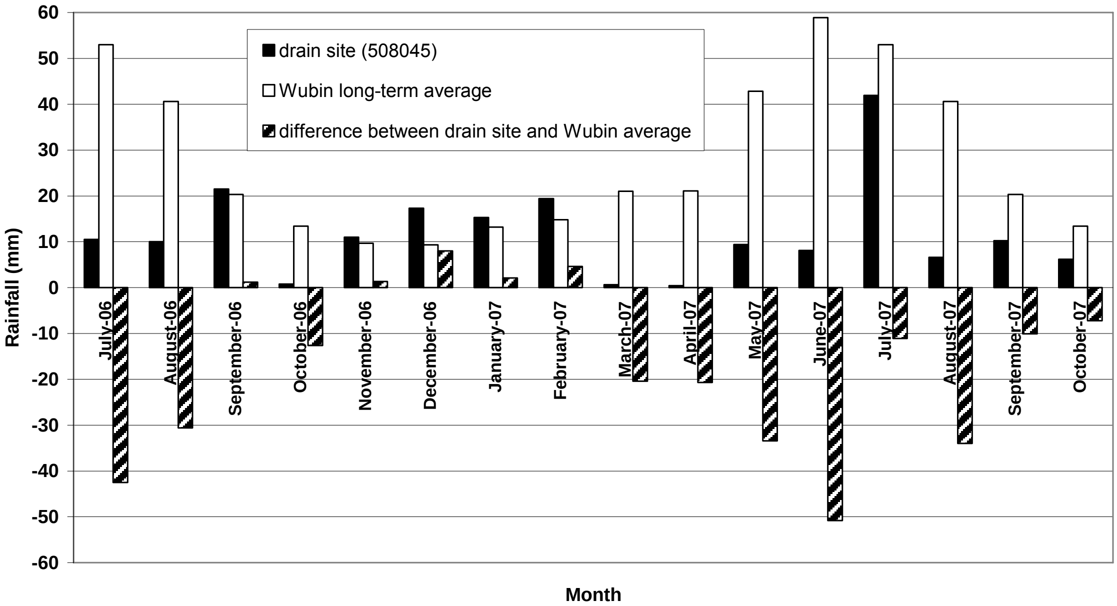

Figure 3 Monthly rainfall at the drain site compared to Wubin long-term averages

2.3 Soils

The soils at the trial site are saline, sodic and subject to high rates of slaking and dispersion. In some parts of the drain this led to rapid erosion, largely with raindrop impact and runoff from the adjacent drain structures. Raindrop impact caused sheet erosion over the entire drain structure and runoff from the berms resulted in rill and tunnel erosion of the batters (Fig. 4).

Soil texture was highly variable across the site, particularly in the upper 1.0 m where it ranged from red-brown loam to silty clays. The red brown loam was the most unstable and tended to crumble even without rainfall. Lime nodules, evident in some of these upper profiles, were randomly distributed across the site.

Figure 4 Sheet, rill and tunnel erosion were visible on all of the drain batters

Subsoils consist of uniformly distributed medium textured grey clay, mottled from 20–60% with red-brown sandy clay loam and cemented nodules. The groundwater that seeped through this clay profile was acidic and appeared rich in dissolved metals such as iron (Fig. 4).

Mapping the distribution of soil profiles across the site to draw any relationship between soil types and the erosion rates of the drains has not been attempted.

3 Project description

3.1 Trial site design

Two parallel lateral drains were constructed 400 m apart extending south from the south side of a collector drain (Fig. 5). The drains incorporated the specifications of three drain designs with different cross sections, referred to as treatments (Fig. 6).

Each treatment extended for 100 m and joined end to end. A section of drain consisting of all three treatments formed a replicate. Replicates 1 and 2 were incorporated into the western lateral drain and replicate 3 the eastern lateral drain (Fig. 5). Both lateral drains have at their upstream ends short sections of standard drain that were not measured.

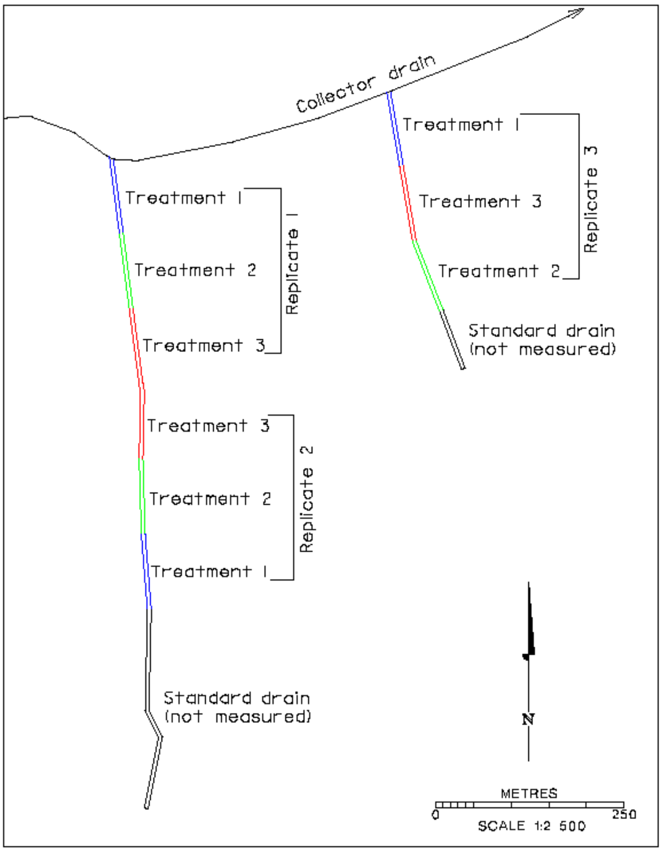

Figure 5 Layout drains and placement of treatments within each of the three replicates

The treatments were randomly positioned within each of the three replicates. The purpose of the replication was to ensure that the individual treatments were exposed to the range of soil and drain-flow conditions.

Earthworks for the three treatments were dug using a bucket excavator to a depth of approximately 2 m, and consisted of (Fig. 6):

- Treatment 1: a trapezoidal drain channel with a 1:0.5 batter slope, 1.2 m floor width, and cross sectional area (CSA) of approximately 4.4 m^2.
- Treatment 2: stepped side batters, each with two benches between ground level and drain floor and a 1.2 m floor width. Each bench and each step-up was approximately 0.65 m wide forming an average 1:1 batter slope and CSA of 5.4 m^2.
- Treatment 3: also a trapezoidal channel similar to treatment 1 but with a 1:1 batter slope and CSA of 6.4 m^2.

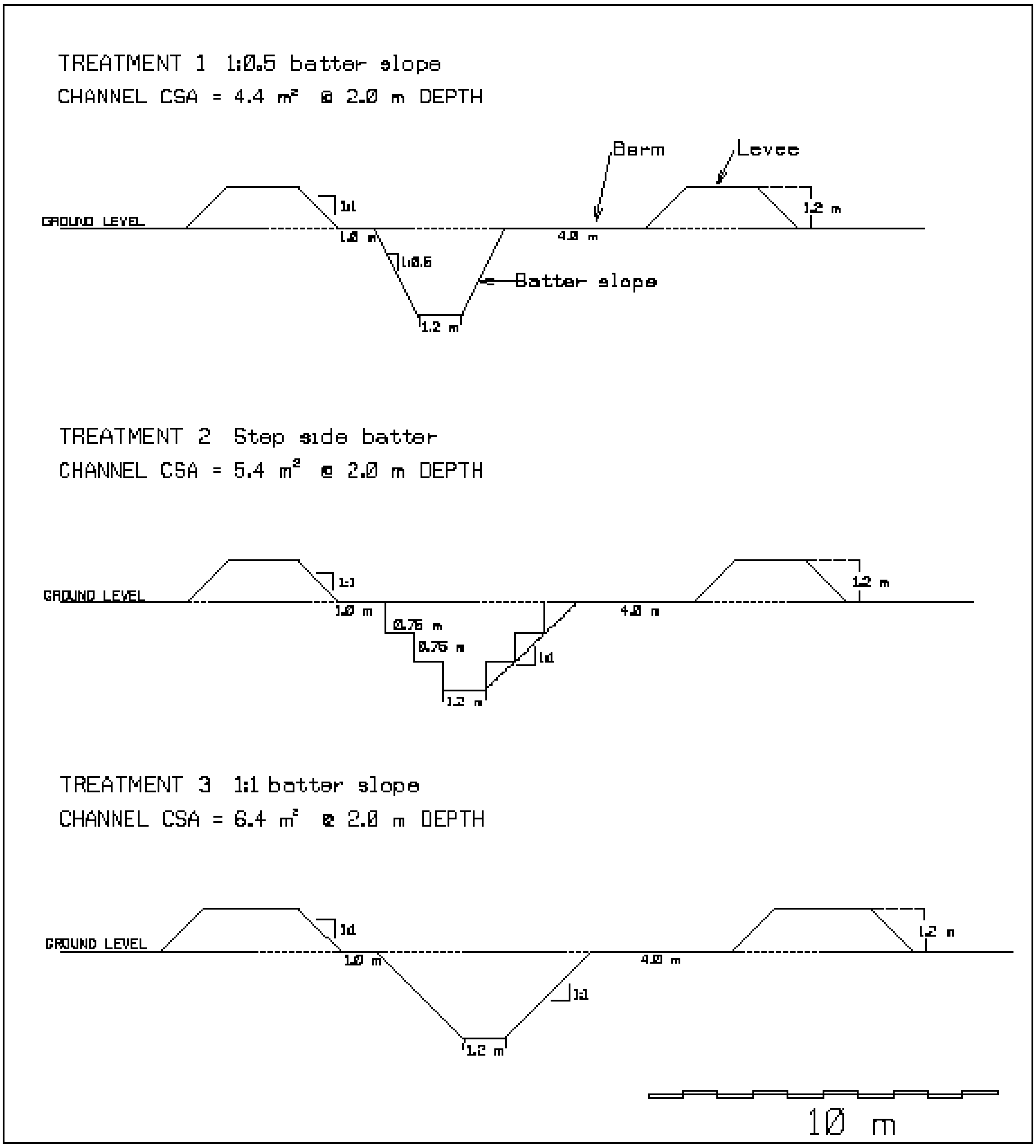

Figure 6 The three drain channel treatments

All drains were within levee banks formed along each side from the excavated soil. The levee banks exclude surface runoff from the surrounding land entering the drain and reduce uneven batter erosion.

With levees in place, drain discharge is from seepage of groundwater into the channel and runoff from within the drain structure. Discharge from both lateral drains was estimated to be less than a maximum of a couple of litres per second.

Runoff within the drain structure, especially from the sides of the levees, can erode batters directly into the channel. To investigate ways of mitigating this runoff, treatments were designed with 1- and 4-m berm widths (Figs 6 & 7). For treatments in replicates 1 and 2, the 4-m wide berm is on the eastern side and in replicate 3 on the western side of the channel.

Figure 7 Treatment 3 (foreground) changing to treatment 2 (background) with the 4-m wide berm on the left side of the channel

3.2 Measurements and observations

Surveys

To measure the surface level change of the drain structure, cross sections of each treatment were precisely surveyed on three occasions:

- Survey 1 — 24/10/2006, within a month of construction to capture the initial cross sections
- Survey 2 — 2/5/2007
- Survey 3 — 8/10/2007, after the winter rains

For each treatment two cross sections were surveyed, one at the midpoint (50 m) and the other at 25 m nearer the drain outlet. A total of 18 cross sections were surveyed across the three replicates on each of the three surveying occasions.

To ensure the same profile was surveyed on each occasion the alignment of the surveys was maintained by control pegs at the top of the levee banks on each side of the drain. To reduce the chance of movement associated with the settlement of the levee banks the control pegs were driven in to their full length of 900 mm.

Vertical and horizontal measurements were taken with a Total Station electronic theodolite with a 5 second arc tolerance. The surveys included the tops of the control pegs and points along the cross section. The cross section elevations from the three surveys were related to the elevation of the control pegs on the 4-m berm side of the drains which were given an assumed elevation of 10.000 m (Fig. 8).

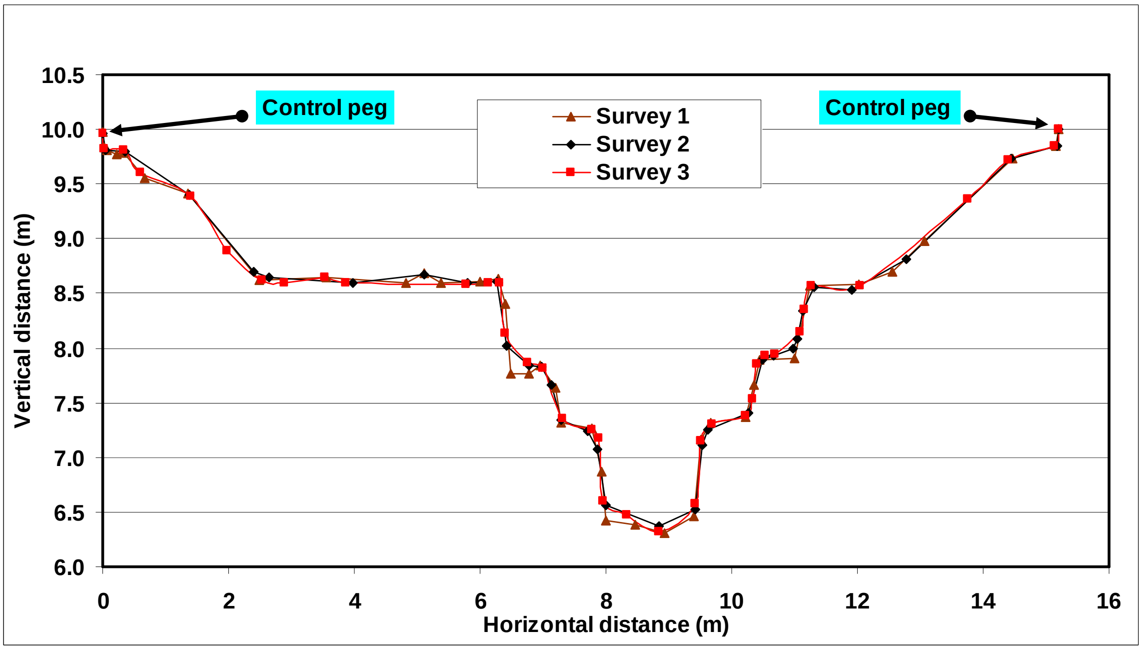

Figure 8 Cross section surveys at 25 m above downstream end of treatment 2 in replicate 1

The estimated range of vertical and horizontal error between each of the three surveys is +-20 mm. This estimation is based on a comparison of the measured differences in position of the control pegs.

The amount of error between points in any one survey cannot be expressed with any quantifiable degree of uncertainty. This is because the individual points surveyed along each cross section alignment were measured as ‘side shots’ from the instrument. The relative positions of side shots were measured from four survey stations located on the berms that formed a closed traverse across the trial site.

Standard survey practice includes ‘closing’ the survey by moving the instrument from station to station, ending on the station from which the survey started. The vertical and horizontal difference in position ascribed to the starting and ending station is used to express the amount of error within the survey. For the three surveys undertaken, the closed traverse produced a maximum rate of error of 1:14 000. Based on a maximum distance between the instrument and any of the individual side shot points, the maximum position error for any point should have been +-10 mm.

The amount of uncertainty in relation to the changes in CSAs has been expressed as the vertical error of +- 20 mm from above, multiplied by the length of each individual drain component (Appendix CD 4.0). In most cases the amount of uncertainty exceeds the change in CSA between surveys (Table 1) except for the drain floor (FL) components.

The adjusted survey results and 18 charts relating to each of the surveyed cross sections are in Appendix CD 3.2a, an example of which is given in Figure 8.

Photographs

A set of four photographs (Fig. 9) was taken during the first and last surveys from the 75 m (downstream) point of each treatment to record:

- The inside of the channel showing sediment accumulation on the channel floor (a)
- An overview of the channel showing the batter condition and berms (b)
- A perpendicular close up showing the batter on the narrow berm side of the drain (c)
- A wide perpendicular view of the drain showing both berms (d)

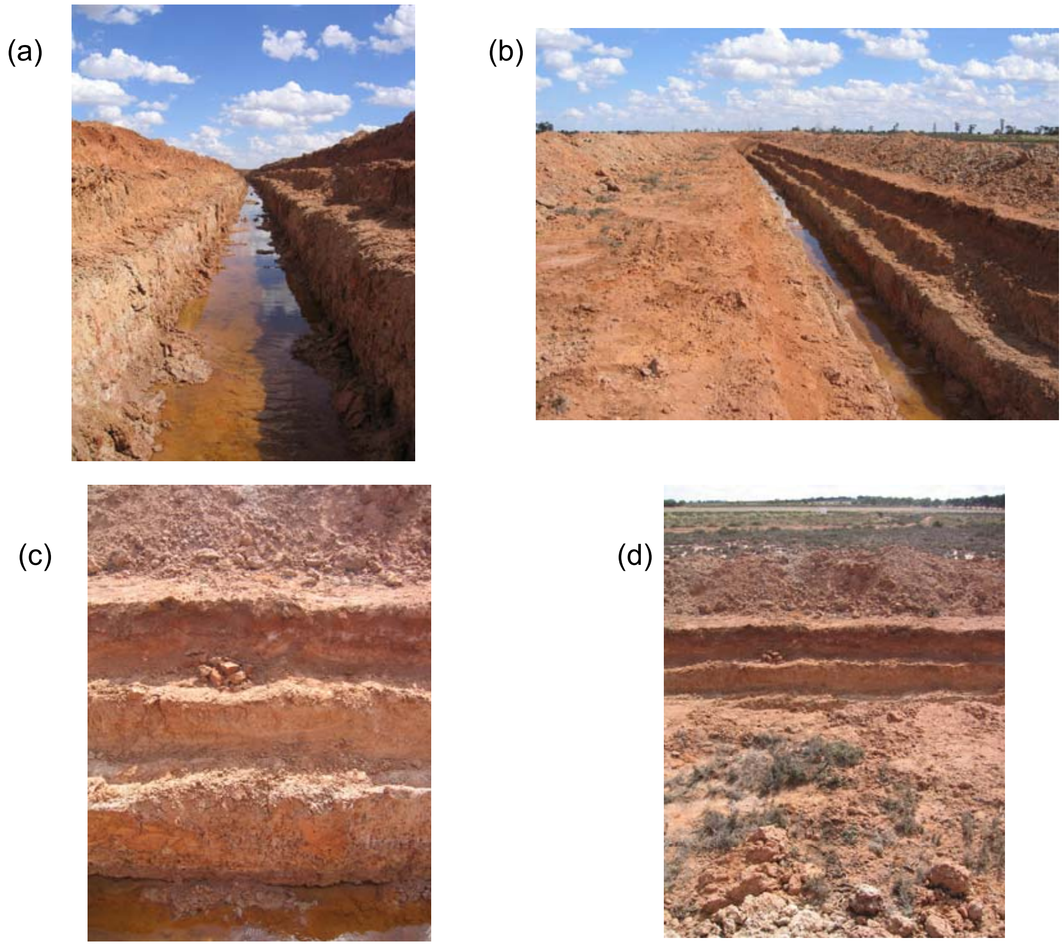

Figure 9 The photo monitoring set (a) inside channel showing sediment on floor (b) channel overview showing batter condition and berms (c) perpendicular close-up of batter on narrow berm side (d) wide perpendicular view showing both berms of step batter (treatment 2) in replicate 1

The full sets of photographs have been provided in CD Appendix 3.2b (24/10/2006) and 3.2c (8/10/2007).

Rainfall

Between the first and last surveys rainfall recorded at the site was 141 mm (Section 2.2) (Fig. 10). Between the first and second surveys, in a period of 190 days through spring 2006 and summer 2007, 65.6 mm of rain fell, with a daily maximum of 18.4 mm, recorded on 25/02/07. Between the second and third surveys, in 160 days over winter 2007, 75.4 mm of rain fell, with a daily maximum of only 7.3 mm, recorded on 3/07/07.

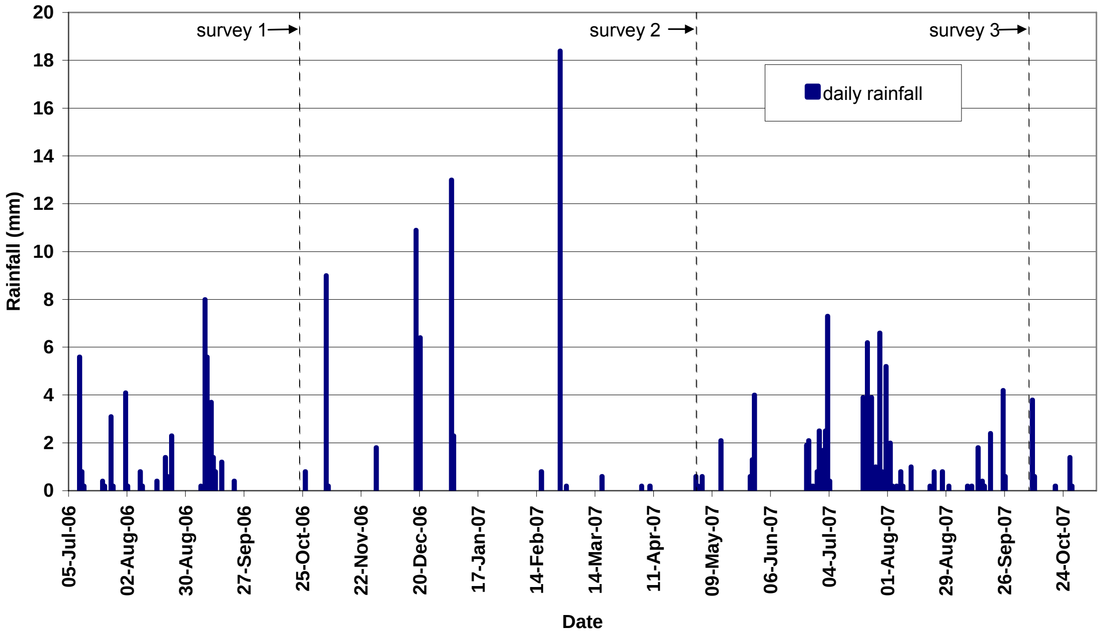

Figure 10 Daily rainfall at Wubin drain site

4 Results

4.1 Treatment performances

The difference between the cross section elevations of the first and subsequent surveys formed cross sectional areas which equated to the loss or accumulation of soil. Changes in drain CSA were calculated firstly from the first and second and finally from the first and third surveys. The results for each of the three treatments were averaged and expressed as change in CSA (Table 1) for the seven drain components (Fig. 11):

- WBL: inside of levee bank above wide berm
- WB: wide berm
- WBB: batter below the wide berm
- FL: drain floor
- NBB: batter below the narrow berm
- NB: narrow berm
- NBL: inside of levee bank above narrow berm.

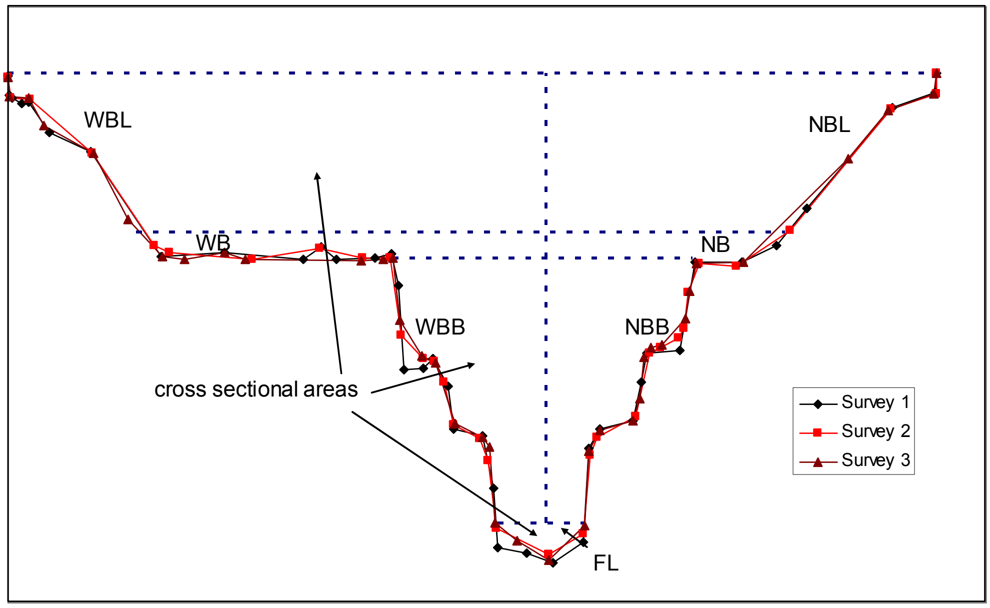

Figure 11 Profile of step batter drain showing cross sectional areas of drain components

A decrease in CSA resulted in a positive value and indicated an accumulation of soil while an increase in CSA resulted in a negative value indicating a loss of soil (Table 1, Figs 12 & 13).

Table 1 Average changes in CSA (m^2) for the drain components within each treatment

Surveys	Treatment	WBL	WB	WBB	FL	NBB	NB	NBL	All
1–2	1	-0.016	0.011	-0.043	0.116	-0.012	0.003	0.074	0.13
1–2	2	0.072	-0.006	0.042	0.062	-0.025	-0.030	0.004	0.12
1–2	3	0.025	0.048	-0.064	0.062	-0.012	0.036	0.025	0.12
1–3	1	0.019	-0.021	-0.067	0.167	-0.016	0.004	0.077	0.16
1–3	2	0.102	0.029	0.109	0.090	-0.022	-0.018	0.032	0.32
1–3	3	0.002	0.041	0.005	0.105	-0.033	0.010	0.044	0.17
Uncertainty (+-)	1	0.060	0.061	0.042	0.029	0.041	0.060	0.051	0.060
Uncertainty (+-)	2	0.057	0.066	0.061	0.026	0.060	0.058	0.064	0.057
Uncertainty (+-)	3	0.060	0.061	0.064	0.026	0.064	0.050	0.062	0.060

The CSA of the drain structures decreased in all treatments, indicating net soil accumulation. The average CSA of the drain structures had decreased in survey 2 by 0.12 m^2 for treatments 2 and 3 and by 0.13 m^2 for treatment 1. By survey 3 the reduction was 0.16 m^2 and 0.17 m^2 for treatments 1 and 3 respectively and 0.32 m^2 for treatment 2 (Table 1).

The average change in CSA of the drain components in each treatment (Table 1) is shown as the average depth of soil lost or gained in Figures 12 and 13. The only results not consistent with what was expected are those for WBL and NBL. These drain components have accumulated soil where the expectation was that they would erode and deposit soil on their adjacent berms and possibly into the drain channel.

For all treatments the amount of sediment accumulated on the drain floor consistently increased from survey 1 to survey 2 and from survey 2 to 3 (Figs 12 & 13). All of the drain batters except for WBB in treatment 2 experienced a net soil loss.

The 1:0.5 batter drain (treatment 1) appeared to lose the most soil from its batters and accumulate the most sediment on its channel floor while the step batter drain (treatment 2) accumulated least sediment on its channel floor.

The survey data showed that the step batter eroded least and accumulated the least soil within its channel floor, which suggests that it was the most stable design. Yet field observations and photographic monitoring contradict this. Generally, the step batter is the most unstable design and the reason this has not been captured by this evaluation is that most of the eroded soil has remained on the benches above the drain floor (Fig. 14) so the CSA of the batters has not decreased.

The loose soil has a lower bulk density than when it was in-situ in the soil profile. This, in combination with the entrapment of soil washed from the berms resulted in the apparent increase in the CSA of WBB for this treatment (Fig. 13).

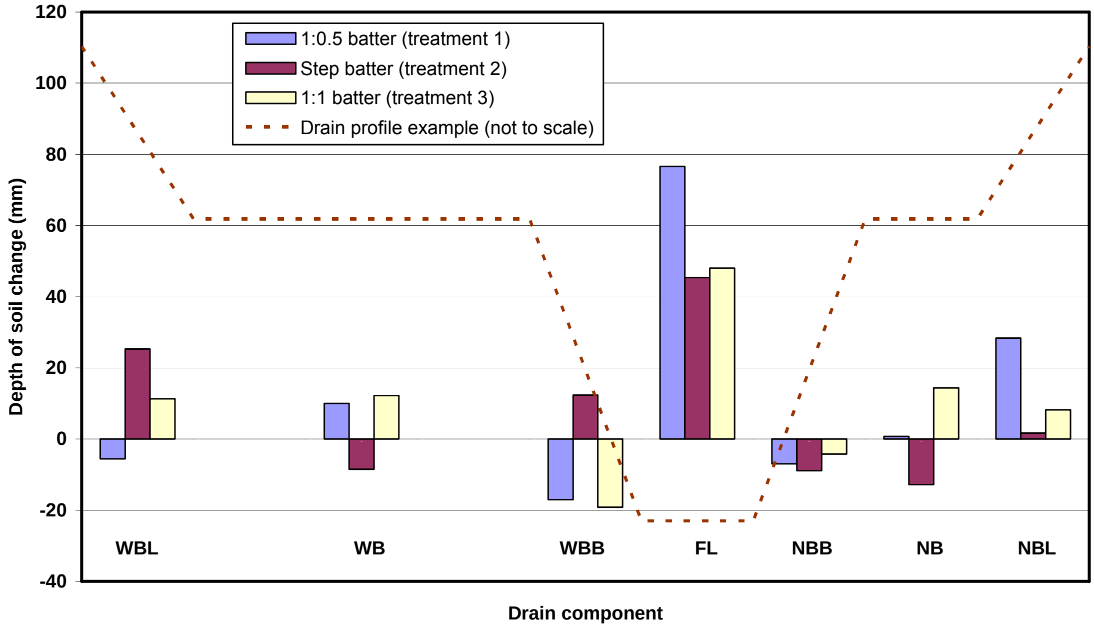

Figure 12 The average change in soil depth by drain component and treatment from survey 1 to 2

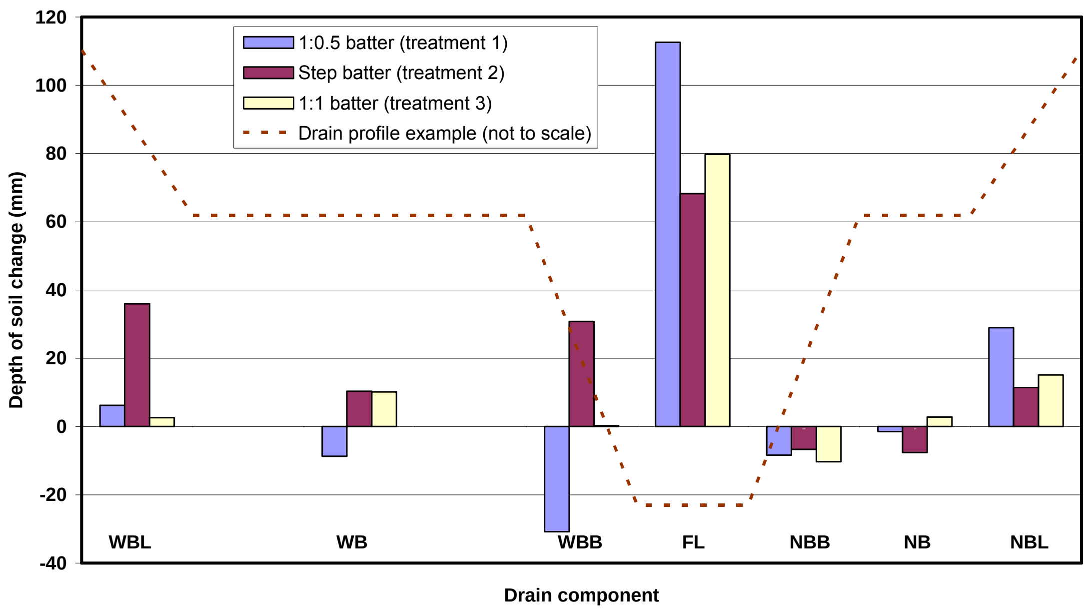

Figure 13 The average change in soil depth by drain component and treatment from survey 1 to 3

Figure 14 The step batter breaking down but holding the eroded material on the benches

This difference between the measured and observed batter stability for treatment 2 came about because of the measurement techniques used in relation to the low rainfall and the relatively short (12 month) trial. Over time, more eroded material will be deposited on the benches and washed into the drain channel. Further rainfall is likely to significantly increase the rate of erosion of this loose soil. This ongoing loss of soil from the batters to channel floor would become more noticeable in future measurements.

This being the case, both the survey results above and photographic record show that the 1:1 batter drain (treatment 3) is the most stable (Fig. 15). A close inspection of the surface of treatment 3 batters reveals that soil detached from the surface is less likely to be shed from this flatter batter to the drain floor.

Figure 15 This section of treatment 3 channel has remained very stable throughout the trial

The steeper batters of treatment 1 also have less detached soil than the stepped batters of treatment 2 so treatment 1 is the second most stable design (Fig. 16). Treatment 1 batters do not have the sharp 90° protrusions at the edge of each bench that predispose the stepped batters to erosion. The overall length of the batter slope in treatment 1 is 2.2 m from top to bottom, compared with 3.3 m for treatment 2. These contributing factors tend to support the photographs that show the smooth short batters of treatment 1 are less likely to erode than step batters.

Figure 16 A section of treatment 1 channel with limited erosion at the 3rd survey

4.2 Berm width responses

To express batter erosion rates in response to berm width, the average measured change in soil depth for each drain component was calculated from all nine treatments and the results for the WBB compared to the NBB.

The batters beneath the wide berm (WBB) eroded less than beneath the narrow berm (NBB) (Fig. 17) with negligible change beneath the wide berm (an overall average gain of 0.1 mm of soil) while the batters beneath the NBB lost 8.4 mm of soil.

A greater depth of soil was eroded from the narrow berm (NB) with an average 2.1 mm depth of soil lost over all treatments (Fig 17). During the same period the wide berm (WB) accumulated an average depth of 3.9 mm of soil, equivalent to an increase in CSA of 0.016 m^2.

The soil accumulated on the wide berms probably eroded from the levee banks (WBL). The eroded material from the levee banks at the narrow berms (NBL) did not accumulate on the berms, and was more easily transported directly into the drain channel. This is evident along some sections of the drains where small gullies have been formed, connecting the toe of the levee banks with the drain batters (Fig. 18).

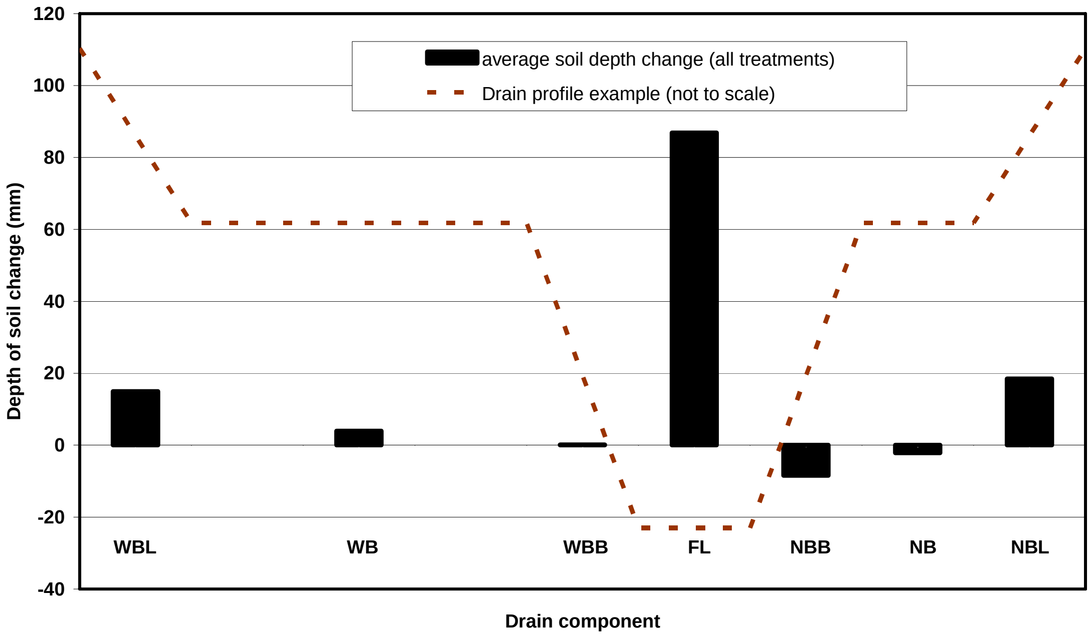

Figure 17 *Average change in soil depth by drain component for all treatments from surveys 1 to 3*

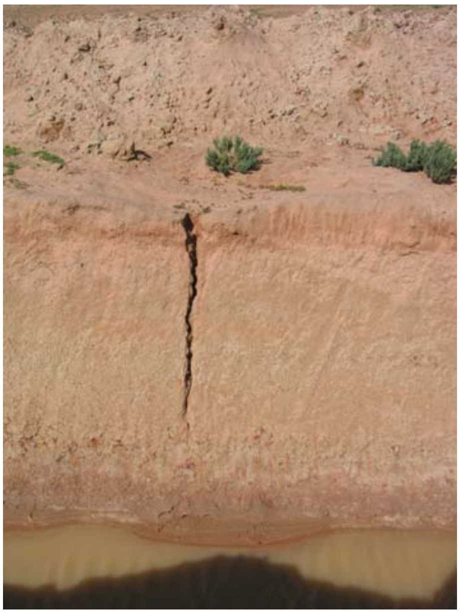

Figure 18 *Eroded soil from the levee bank is easily transported across the narrow berm into the drain channel*

5 Discussion

The rates of erosion of the drain structure, particularly the batters, contribute to the rates of sediment accumulation on the channel floor. Because these drains carry mostly groundwater seepage, the flow rates are usually insufficient to wash sediment along the drain to downstream silt traps. As the sediment depth increases effective drain depth decreases along with its efficiency at lowering the surrounding watertable.

As a guide, Wheatbelt drainage practitioners agree that de-silting of the drain is required once sediment depth on the drain floor reaches 500 mm. De-silting is done using an excavator equipped with a wide shallow bucket (batter bucket) and operated from the side of the channel. The de-silting currently costs in the order of $1000/km ($1.00/Lm).

At the measured rates of accumulation, the step batter (treatment 2) channel will have 500 mm of sediment after 6.7 years. Though the measured rates of batter erosion and sediment accumulation for the 1:1 batter drain (treatment 3) were higher, de-silting will only be needed after 8.1 years. This is because the channel floor of treatment 3 can accommodate more sediment before the depth reaches 500 mm (Fig. 6) so will take longer to fill.

The 1:0.5 batter drain (treatment 1) will theoretically need de-silting 4.65 times over a 20 year period (every 4.3 years) at a total cost of $4.65/Lm (Table 2, row *b*). Treatment 2 will require de-silting 2.98 times, and treatment 3, 2.47 times over a 20 year period and at a rate of $1.00/Lm the total de-silting costs would be $2.98/Lm and $2.47/Lm respectively (Table 2, row *b*).

Most drainage contractors are equipped to dig drains of treatment 1 design cost effectively. In this trial, the cost of the treatment 1 drain was $6.50/Lm (Table 2, row *a*) or $1.48/m^3. Based on this cost per cubic metre the costs of excavating the treatment 2 and 3 drains are $7.98 and $9.45 respectively.

Treatment 2 is calculated to be the most cost-effective option when combining the cost of excavation and de-silting over a 20 year period (Table 2, row *c*). These calculations are based on the first 16 months after construction when sediment tended to deposit on the step batter benches. It is expected that the rate of sediment accumulation on the channel floor will increase over time. If extra de-silting is required to maintain the function of this drain then its cost effectiveness is reduced. The total cost of excavating and de-silting treatment 1 is $0.19/Lm more than for treatment 2, probably making it the more cost-effective in light of the above.

The efficiency of an excavator is improved by using specially shaped buckets that suit the shape of the drain channel being excavated. The 1:0.5 batter trapezoidal channel of treatment 1 required limited measurement and precision machine operation and could be readily excavated with an appropriately shaped bucket. This allowed the machine to excavate the drain and cut the batter slope from end on, whilst proceeding along the drain alignment.

As treatments 2 and 3 required precision machine operation or extra passes of the excavator to remove loose soil or cut the required batter slope, the actual costs of digging these drains were nearly twice that of treatment 1 (Table 2, row *d*).

The CSA and actual cost of excavation of treatment 3 was 50% greater than for treatment 1 (Table 3, row *d*), somewhat negating the benefits it offers in terms of reduced sedimentation and de-silting costs.

Table 2 Excavation and de-silting costs over a 20-year period

		Cost ($)		
		Treatment 1 1:0.5 batter	Treatment 2 Step batter	Treatment 3 1:1 batter
a	Digging cost /Lm @ $1.48/m^3	6.50	7.98	9.45
b	De-silt cost /Lm over 20 years	4.65	2.98	2.47
c	Total cost /Lm over 20 years	11.15	10.96	11.92
d	Digging cost /Lm @ actual cost/m^3	6.50	10.80	12.50
e	**Total cost /Lm over 20 years @ actual cost**	**11.15**	**13.75**	**14.97**

The harsh and saline nature of the trial site combined with the drier-than-average season prevented re-vegetation of the step drain batters. In a less harsh environment sediment accumulating on the batter benches of treatment 2 may have provided opportunities for plant establishment, and in turn improved both batter stability and the appearance of the drain.

Raindrop impact and runoff were not the sole contributors to batter erosion. Due to the high soil salinity, the process of wetting and drying caused the surface soil to break away (Fig. 19), and soil to readily fall onto the channel floor from the steeper batter slopes of treatments 1 and 2.

The detached soil on the 1:1 batters of treatment 3 was less likely to fall off and tended to settle back onto the surface when re-wetted. This is believed to have been partially responsible for the lower rates of batter erosion for this treatment.

For this drain batter trial, there has been insufficient rainfall and time to establish any significant differences between the erosion rates of the three treatments. Many of the numerical results discussed and compared are within the range of reasonable survey errors (Section 3.2). In contrast, the photographic record showed considerable erosion and sedimentation across some treatments. The most significant expected impacts of additional rainfall and time would be a rapid acceleration of soil erosion from the batters of treatment 2 to the channel floor.

Figure 19 The crumbling batters of treatment 1 in replicate 2

6 Conclusion

The 1:0.5 batter drain (treatment 1) is currently the most cost effective to construct and maintain relative to the total costs of the other treatments. Its lower construction cost was more than sufficient to compensate for the additional de-silting required over a 20-year period.

The step batter drain (treatment 2) measurements indicated the lowest rates of batter erosion and sedimentation but were misleading as the photographic monitoring revealed a much greater level instability. In the near future or in response to significant rainfall loose soil will be rapidly transported from the batters to the channel floor. Re-measurement of the step batters should confirm they are the least stable given they could not be vegetated at this site.

The 1:1 batter drain (treatment 3) provided the most stable channel cross section and is expected to continue to exhibit the lowest rates of batter erosion and channel sedimentation.

The erosion of batters below the wide berms was on average less than below narrow berms. This appears to be mainly due to the greater attenuation of runoff from the adjacent levee banks on the wider berms.

These conclusions are based on a set of measurements with values that do not significantly exceed the levels of error associated with the method of measurement. This was largely the result of lower than expected rainfall and limited ensuing erosion. Future surveys of the site could be undertaken to confirm or extend the results of this 12-month trial.

Glossary

Batter	The inside edges of the drain channel that extend from the natural ground level down to the floor of the channel
Batter slope	The slope of the batter expressed as a ratio X:1, vertical to horizontal distance
Berm	The strip(s) of land between the top of the drain channel batter and inside toe of the levee bank
Bulk density	The mass of dry soil per unit volume
Channel	The excavated part of the drain structure that conveys or intercepts water
Collector drain	A main drain that receives and conveys discharge from lateral drains
Cross sectional area	(CSA) The area of a truncated end or section of a structure such as a drain channel (m^2)
De-silting	The mechanical removal of accumulated detached soil from a drain channel
Detached soil	Small soil particles broken away from the soil mass and capable of being removed by erosive processes
Discharge	The total volume of all water that flows from the outlet of a drain or drain section (kL)
Dispersion	The breakdown of soil structure into its constituent particles of clay silt and sand under the application of water
Drain structure	All of the components of a drain: channel, berms and levees (if present)
Erosion	The removal of detached soil by rainfall, wind and moving water
Groundwater	Water within an aquifer below the watertable
Groundwater drain	An excavated channel that penetrates the aquifer for the purpose of draining groundwater
Halophytes	Salt tolerant plants
Hectare	(ha) An area of 10 000 m^2

Kilometre	1000 metres distance
Lateral drains	Parallel drains that extend from one or either side of a collector drain
Levee bank	A continuous mound of earth used to exclude or redirect runoff
Leveed drain	A groundwater drain with the channel completely enclosed within levee banks
Linear metre	(Lm) Measured distance along an alignment or the alignment of a structure
Open drain	A dual purpose groundwater/surface water drain not completely enclosed within levee banks
Replicate	A repeat of a previous treatment
Rill	A small channel cut by concentrated runoff water
Runoff	The volume or depth of water moved over the land surface (kL or mm)
Salinity (specific)	The concentration of total dissolved salts in water or soil (mg/L)
Salinity (general)/salinisation	The reduction in the productivity or biodiversity of land or water due to an excess of salts within the environment
Sediment	Material (soil) that is or has been moved from its site of origin by erosion
Side-shot	The surveyed measurement of a point that is not checked by closing the survey or repeated measurment
Slaking	The breakdown of soil aggregates in water due to swelling of clay and expulsion of air from pore spaces
Sodic soils	Soil containing sufficient exchangeable sodium ions to adversely affect soil stability and land use. Sodic soils are subject to dispersion resulting in erosion
Soil	The natural unconsolidated mineral and organic material at the surface of the land
Step batter	The batter of a drain constructed in a series of steps orientated parallel to the channel floor
Surface water channel	A channel constructed for the purpose of catching and conveying surface water runoff

Total station theodolite	A precision electronic surveying instrument for measuring horizontal and vertical angles and distances
Treatment	A specific set of design and construction criteria applied to sections of drain
Tunnel erosion	Erosion particularly of dispersive/slaking soils where a 'pipe' is formed through the soil between an inlet at the soil surface and the outlet usually into a gully or channel

References

Bureau of Meteorology 2008.

Chandler, KL & Coles, NA 2003, *Review of deep drains to manage salinity in Western Australia*, Miscellaneous publication 2/2004, Department of Agriculture Western Australia.

Schwab, GO, Frevert, RK, Edminster, TW & Barnes, KK 1991, *Soil and Water Conservation Engineering*, John Wiley & Sons Inc, USA.

YYCMG 2008, *Progress Report of the Yarra Yarra Regional Drainage and Research Project, version 1.1,* Yarra Yarra Catchment management Group, Western Australia.

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