WATER FLOW IN MULGA AREAS ADJOINING FORTESCUE MARSH

Report of observations from field trials undertaken for
Fortescue Metals Group Limited

C Muller
January 2005

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Introduction:

The mulga woodlands adjoining the Fortescue Marsh have high conservation significance, and have been proposed by the Department of Conservation and Land Management (CALM) to be excluded from the pastoral leases in 2015 when the current leases expire, and be managed to protect their high conservation values. The health of these woodlands is dependant in part on surface water flows, including sheet flow. Proposed mining and associated infrastructure will interrupt natural flows. The extent and significance of this will be dependent on the allowances made for surface flows to pass around or under any barriers and the success of efforts to re-distribute flows.

Linear infrastructure such as roads and railways running across the slope, along the contour, can affect natural flows for the length of the infrastructure if inadequately managed. Both road and rail have negligible impact on flows in clearly defined drainage lines where water can be passed under (bridges or culverts) or over (floodways) them, however grade requirements for rail can result in cuttings or sections of embankment too low for culverts, where it is impossible to pass water across the line in the original drainage line.

Whilst in most cases flow in well defined drainage lines can be successfully passed across the alignment, both road and rail stop surface sheeting which must be re-established with adequate culverting and sheet flow redistribution. The rail/road embankment acts as a barrier to surface flows, and can result in ponding upstream and drainage shadow downstream of the embankment. Culverts through the embankment at each depression can minimize ponding, but there will remain a drainage shadow on the downstream side until significant sheet flow is reestablished. The extent of the shadow will depend on how quickly water spreads from a point discharge (culvert), and on the spacing of the culverts.

Whilst culverting improvements and sheet flow redistribution methods currently in use in the Pilbara have shown considerable advance on earlier practice, Fortescue Metals Group (FMG) wish to further improve upon current practice in this area, with the aim of eliminating or minimizing water shadow issues to the greatest extent possible. FMG commissioned Cs Muller Consulting Pty Ltd to undertake a study to investigate possible methods of sheet flow redistribution that could be developed further from a conceptual stage, and potentially be applied to FMG's proposed railway during construction.

The initial objective of the study was to observe and record water re-distribution within mulga areas from both culvert sites and from sites where water is channeled to the rises between culverts, in order to better understand surface water flows in mulga communities. It was also designed to trial a number of different sheet flow redistribution methods, to determine their effectiveness and to identify future work that may be required to refine their design.

This study aimed to:

1. Improve our understanding of natural surface flows in mulga communities, including spread from a point discharge such as a culvert.
2. Field trial alternative redistribution structures.
3. Investigate potential significance of subsurface flows from redistribution structures.

Description of trials.

Water Supply and Quality

The primary water supply was from bore E20, with a TDS of 1.05 grams/litre (1,050ppm). This was central to the trial sites.

Due to the low yield of this bore, there was insufficient water available from this source at the time of the trials. Supplementary water was obtained from the bore at Christmas Creek camp (TDS 1700ppm) and the 22 Mile bore (1050ppm). Where the higher salinity water was used, it was diluted in the tanker with water from E20 bore. The TDS of water discharged in the trials ranged from 1050ppm to a maximum of 1460ppm for one load of water at the Grove/Intergrove site: A second load discharged at this site had a TDS of 1050ppm. A summary of the water used in each location is attached (Appendix 1 Data Summary)

Flow rates

The planned discharge rate was 30 litres/sec (half that advised to be the capacity of a 300mm diameter culvert). This could not be achieved because of a faulty pump. Rates of discharge were between 21 and 25 litres/sec.

Surface Flows – Spread from Point Discharge.

Simulations of discharge from a culvert were carried out at five sites. For the first two sites discharge was through a 300mm pipe (the size of culverts proposed by FMG for environmental flows under the railway embankment to facilitate sheet flow re-establishment). Corrugated iron sheets were placed at the discharge point to absorb energy and avoid erosion (Fig. 1).

Experience with the first two trials demonstrated similar point discharge could be achieved via the delivery hoses direct onto the corrugated iron, and the culvert was not used for subsequent plots.

Discharge was continued until an apparently stable discharge fan was established (ie whilst the water continued to spread down slope, lateral spread had stabilized behind the advancing water front). The volumes discharged in individual trials ranged from approximately12,000 litres to 50,000 litres (see appendix 1). Accurate volumes were measured by (before and after) tanker dips to calculate flow rates with different discharge configurations, and in other cases were estimated.

The nature and extent of spread of water was observed, photographed, and the boundary surveyed.

Fig 1: Use of corrugated iron to dissipate energy. Flow rate 23 litres/second.

Sheet Flow Redistribution

Two different methods for distributing sheet flow, after it has passed through a culvert, were trialed:

- Spreader Ditches
- Levee Banks

In addition, subsurface flow was measured from a drainage structure, in order to determine the contribution of subsurface flow to the movement of water down slope.

Spreader Ditches:

Two spreader ditches based on concepts proposed by Aquaterra (Appendix 2) were constructed. Two lines (one 50m in length and one 60m long) were surveyed and pegged to level +/- 5mm. A 0.5m x 0.5m ditch was dug with a backhoe.

In one case the spoil was used to create a line of 5m long earth bunds on the downstream side, with gaps of approximately 1m between the ends of adjoining bunds.

With the other ditch the spoil was placed clear of the ditch on the upslope side with the intent of having a level, undisturbed sill on the down slope side. The down slope side of the ditch required trimming by hand to remove spill from the backhoe to achieve the level sill.

The spreader ditch as proposed by Aquaterra is 100m for a peak culvert discharge of 60 litres per second. As the planned trial discharge was only 30 litres/second, the planned length of the ditch was reduced to 50m ditch so as to maintain similar overflow rates.

One spreader ditch could not be constructed for the full length as pegged due to the hardness of the material encountered, and was reduced in length to approximately 35m. With the reduced flows due to the faulty pump the proportions remained approximately correct and so the ditch was not extended at the other end for the purposes of this trial. Due to the shortage of water and the reduced flow rate, the second ditch was also proportionately reduced in length

Levee Banks

Levee banks were constructed at two sites using river shingle, with the intent that they create a permeable barrier that would slow and spread out the water, with water percolating across a wider area than with unimpeded flow.

At one site the line was surveyed and pegged to be level within +/- 5mm. At the other site the levee was deliberately surveyed to cross the minor depressions and “ridges” (25 mm difference) in the apparently flat terrain.

Levee banks were initially constructed considerably wider than preferable, contained much fine material, and were compacted, resulting in a dam wall of very low permeability. Walls were modified during the course of the trial to allow water to pass through them.

Subsurface Flow:

To test the extent of subsurface flows from drainage structures, a spreader ditch was filled to capacity (but not overflowing). Soil moisture was sampled at three points 750mm down slope from the spreader ditch using a “Speedy” Moisture Meter.

After 16 hours (the following morning) soil moisture was again sampled at the three points and at a control site 4.1m from the ditch, and the ditch refilled.

Soil moisture measurements were again taken after a further 8 hours (ie 24 hours from initial filling of the ditch). The extent of penetration after 24 hours was further examined by excavation with a mattock at right angles to the trench.

Results and discussion:

Surface Flow:

Relationship between slope and spread:

All trial sites were relatively flat, with slopes ranging from 0.22% to 1.75%. As expected, water spread out more on flatter areas. The plots of the boundary of the point discharge sites are attached (Appendix 3). From these plots the average angle of spread was determined, and the relationship between angle of spread and slope plotted (fig 2).

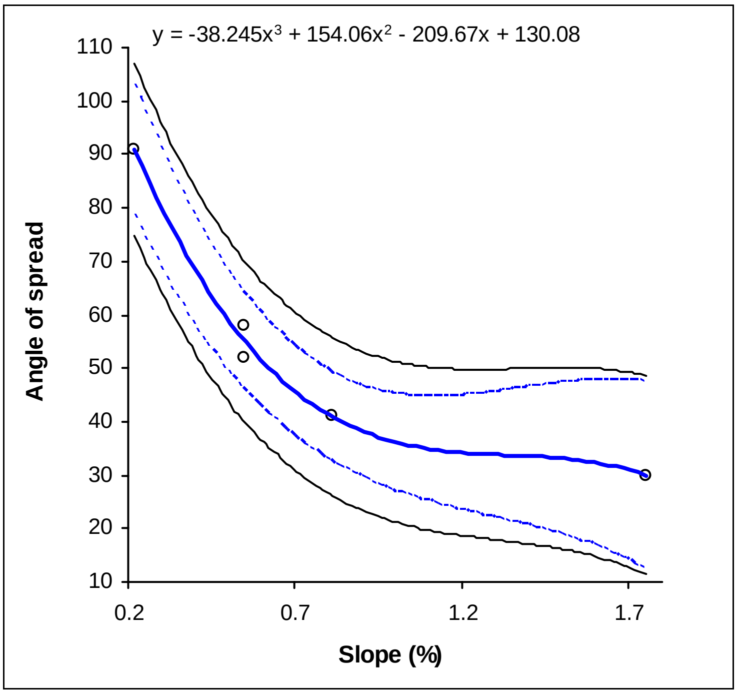


Fig 2 : Relationship between angle of spread and slope from 5 sites sampled.
r^2= 0.97, SE = 4.2426

Given the limited sampling sites, there is a high standard error and the above results need to be treated with caution, however it does provide a guide to the spread and potential extent of drainage shadow that can be expected within the range sampled. Results should not be extrapolated beyond the range of slopes sampled, but the distance (*d*) before spread equals distance between culverts (in the area sampled) can be calculated by:

$$d= s /2 \tan(a/2)$$

where

s = culvert spacing
a = angle of spread

For example, if conditions remain similar (ie no intervening creeks, etc) for culverts spaced 100 metres apart on a !% slope, it would take between 120 m and 207 m (mean 153 m) before sheet flow is established. Note: the above calculation is based on limited information and should be treated with caution in attempting to predict the extent of drainage shadow.

Sheet Flow:

The term sheet flow is misleading in that it implies more or less uniform flow of water across broad areas. From observations during this trial this is only superficially the case. The surface that appears flat to the naked eye comprises a series of shallow ridges and depressions (see Figures 3a and 3b).

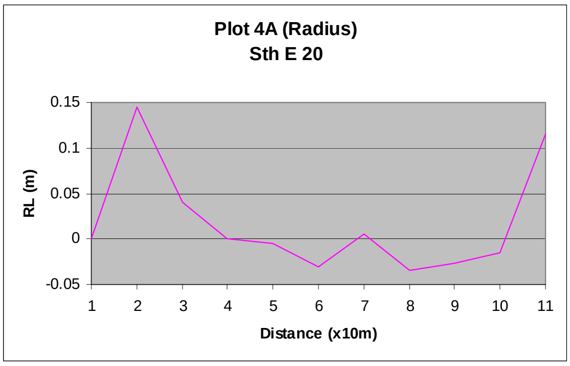


Fig 3a: Relative levels on plain around E20 levee plot levee

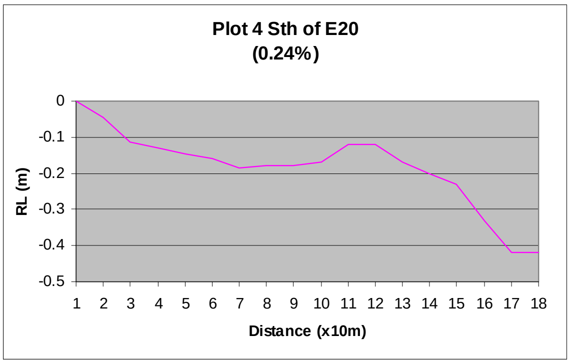


Fig 3b: Initial survey of E20 levee site levels prior to construction.

The undulations are evident as wet and dry patches on the ground after the water has drained from the site trial (fig 4).

Fig 4: View of "E20 Levee" site the day after the first discharge trial. The depressions are evident as darker patches.

The extent to which water is restricted to depressions or spreads following discharge from a culvert depends on the height of the intervening "ridges", the flow from the culvert, and any obstructions encountered. If the rate of flow is sufficient such that the depth of water is greater than the height of the "ridges", the water will spread. Similarly, if water flowing down a depression encounters an obstruction such that it builds up and overflows the ridges, it will also spread.

The effectiveness of barriers in increasing the depth and spreading the water is well illustrated in figures 5a and 5b. The initial spread is not at the barrier itself, but slightly before the barrier, where the ground is slightly lower. The barrier acted to bank up the water, which first overflowed at the lowest point encountered.

Fig 5a: E20 Levee site facing south. The "head" has reached the levee wall. Further spread is initially along lower areas back from the wall.

Fig 5b: E20 Levee site. Spread of water along levee wall.

On the "Grove/Intergrove" site the water spread laterally before reaching the grove. Prior to the trial, it was anticipated that the mulga grove would act similar to the levee, as an obstruction to spread the water. This proved not to be the case. The water spread out before reaching the grove, and there was much less spread within the grove itself. (see Figure 6 and Appendix 3). A possible explanation for this is that the grove has acted over the years as a silt trap and/or reduced sheet erosion and as a result is marginally higher than the surrounding land, resulting in the water spreading in the marginally lower areas immediately before the grove. The differences in levels are slight, and are less than the overall fall towards the grove. The density of sampling points in the survey carried out prior to the trial was insufficient to identify this small change over a large area evidenced by the water flow.

Fig 6: Main spread of the water was prior to reaching the mulga grove.

With increasing slope, the drainage is more clearly defined and more deeply incised. The trial plot with the greatest slope (1.75%) was adjacent to a defined drainage line. Perhaps surprisingly, within the 45metre length of spread, the water did not spread towards this drainage line, but away from it (see Appendix 3 and figure 7). Heavy sheeting on quite steep hillsides has previously been noted by the author near Marandoo and elsewhere in Karijni. It is evident that whilst there is a higher concentration of water within creek lines, this is only a fraction of the water sheeting from slopes. The sheet flow in mulga areas is not solely from creeks fanning-out, and "hillside sheeting" may be significant for at least those communities on lower slopes.

Fig 7. Discharge and spread at the "steep" site (Slope 1.75%). Note creek line (indicated by the row of trees) in background. The water did not flow towards this creek, but sheeted parallel to and away from the creek.

Redistribution/Spreader Structures.

Both spreader ditches successfully spread water at higher flow rates (Figure 8. 9a and 9b), with a higher flow at slight depressions along the ditch sill. However at less than peak flow rates there was strong preferential discharge to one or two lower points only, with flow ceasing at other points. Thus, unless the culvert is running at near capacity, the spreader ditch will relocate the water to this lowest point, but not spread it out. This will be exacerbated if there is any erosion at these discharge points.

Fig 8: Spreader ditch with bund on down slope side. Note the breaks in the bund in the centre and left of the picture have been affected by cattle trampling, with the one in the centre of the picture completely closed.

Fig 9a: Unconfined channel. Flow rate 21.5 l/sec. Ditch overflows at multiple points.

Fig 9b: Reduced flow. Discharge at low point only.

It is difficult/impossible to establish the sill exactly level. Whilst the survey line was pegged to within 5mm, there is inevitable disturbance during construction. Care was taken to leave the down slope side of the lower channel undisturbed. Spill from the backhoe was removed by hand along the down slope side of the “unconfined” ditch.(Figure 8). Despite this, there was preferential discharge (Fig 10).

Fig 10: Minimal disturbance of natural surface to retain level. Spill removed by hand.

Maintenance of spreader ditches is likely to be a major issue. The upslope (culvert) side of the ditch is susceptible to erosion as it fills (Figure 11) and rock armour may be required.

Cattle are also likely to cause major maintenance issues. In the short period between the mounds being constructed and the trial, cattle had trampled the mounds below the spreader ditch, effectively closing two of the openings, even with no water in the ditch. Within 24 hours of the ditch being filled, cattle had trampled both the ditch and the mounds (Figure 12). The problem was probably exacerbated in this case as the surrounding country was dry, and it may be less of a problem during a natural flooding event, however, as the ditches will retain water for a longer period, they will still be a “watering hole”, and attract cattle.

The adjoining levee bank trial also retained water and attracted cattle, but suffered little/no damage (figure 13) during the course of this trial. Maintenance would undoubtedly be required in the longer term.

Fig 11: Ditch edge may need armouring to prevent erosion.

Fig 12: Cattle damage 24 hours after filling.

Fig 13: Cattle trampling did not materially affect the levee bank.

The levee spread water successfully (figures 5a and 5b) but did not allow water to pass as constructed. The levee banks at both sites were modified to make them narrower. They were not uniform, and the variation provided some indication as to the requirements for successful permeability. (Figures 14 and 15). The levee at the “top” site (Figure 15) was constructed quickly by tipping from a loader bucket. The resultant levee is far from uniform, but successfully passed water at a number of points along its length, sufficient to ensure effective spread for the length of the levee. This shows considerable promise for both simple construction and maintenance.

Fig 14: “E20 Levee”. This had a high proportion of very fine material, and insufficient permeability, and it is likely it would have eventually over-topped with sufficient water. Effective at spreading the water.

Fig 15: “Top” levee. The front levee was constructed quickly with a loader. The original levee in the rear was too wide and consolidated for the purpose. Permeability was not uniform, but the levee leaked in sufficient places that continuous sheet flow was quickly established.

This trial was limited by the material available. The preferred material would be ballast size crushed rock. Due to the limitations of the pumps, the trial could not test the stability of the narrow levee to a full discharge event. In practice it may be necessary to confine the section of levee in the culvert discharge area with wire mesh (gabions or reno mattresses).

The trial could also not establish the extent to which such levees would silt up, however, the non-uniform material used contained a considerable amount of fines making some sections relatively impermeable. This did not affect the overall performance, as there was still sufficient discharge at point along the line.

The levee showed promise as an effective and cost-effective method for spreading water quickly. Considerably more work is required to determine the optimum material and size of the levee to slow the water sufficiently to ensure spread, but with minimal impediment to through-flow. Possible further work that FMG may choose to conduct to improve its understanding of these issues is outlined in the conclusion to this report.

Subsurface Flow

In 24 hours, the maximum progress of subsurface flow from a spreader ditch was 900mm, and therefore is not a significant contributor to water spread.

There was no noticeable increase in moisture content ahead of the obvious colour change. The measured moisture content 2 cm ahead of the obvious boundary was 4.3%, and immediately behind the boundary 16+%.

Fig 16: Penetration after 16 hrs (above) and 24 hours (right)

Fig 17: Extent of lateral moisture movement through the soil in 24 hours. Maximum movement was approximately 150mm below the surface. Moisture content 2cm to the left of the obvious boundary was 4.3%.

Conclusions

The spread of water from a discharge point decreases with increasing slope. Establishing infrastructure on relatively steeper slopes within mulga areas, or upslope in areas where there is significant "hillside sheeting", is therefore likely to cause the greatest difficulties in spreading water, and re-establishing sheet flow. The flatter the area, the more rapid the spread of water and sheet flow re-establishment, and the smaller the potential drainage shadow for any given culvert spacing. Thus potentially rail infrastructure established upslope may have higher drainage impacts than rail established in mulga flats themselves.

Establishing railways within the mulga flats would therefore appear preferable to a railway higher in the mulga or immediately above mulga communities with respect to sheet flow drainage, provided there are adequate culverts and spreaders. However, significant borrow would be required to ensure sufficient embankment height to permit culverts.

Establishing infrastructure a sufficient distance upslope does potentially allow the capture of surface flow in defined channels and subsequent redistribution above the mulga areas. Culverts in channels can reduce the overall embankment height, but increases the difficulty of re-distribution of the water "trapped" in the channels, particularly where these are more deeply incised. Where there is significant "hillside sheet flow" it is desirable to minimize diversion. It is apparent however, that companies working in sheet flow areas, must attempt to maintain a balance between being higher in the landscape to capture surface water in defined channels with reduced “borrow” requirements for embankments, and being lower in the landscape to enable the re-distribution of sheet flow. The particular combination of approaches adopted may be different on a case by case basis, to enable the greatest net benefit in terms of managing surface water flows and disturbance impacts.

Permeable levee banks offer promise to redistribute water effectively and cheaply. Close culvert spacing and overlapping levee banks could potentially virtually eliminate drainage shadow.

Surface flows were significant on all slopes within the study area (which was at 425-445m elevation), including where there are clearly defined drainage lines. In order to minimize impacts on mulga communities, consideration should be given to reestablishing broad surface flows below mine sites as well as infrastructure, at least on the lower slopes.

Sub-surface flow is not significant in water distribution in the mulga communities studied.

Recommended Further Work

To build on the current level of understanding and the findings of this study, it is recommended that FMG consider the following further work:

- Conduct trials with a range of graded crushed rock material from likely sources to determine optimum material for levee bank construction to provide the balance between spread and permeability. Such trials should include:
    - heavy sediment loads to provide accelerated siltation so as to investigate long term performance
    - varying widths of levee to determine the maximum width that will provide the desired permeability
    - assessment of the resistance to cattle damage

- Investigate the susceptibility to erosion/damage of the spreader levees under full discharge plus head for the design return period event for the railway line, and determine if gabions or similar are required at discharge points.

- Investigate the maximum effective length of spreader levee for a range of rainfall events, from the minimum that is expected to result in overland flow, to the maximum design criteria discharge event. This will assist in design of effective culvert spacing in areas where sheet flow is to be re-established.

Appendix 1: Data Summary

DATA SUMMARY

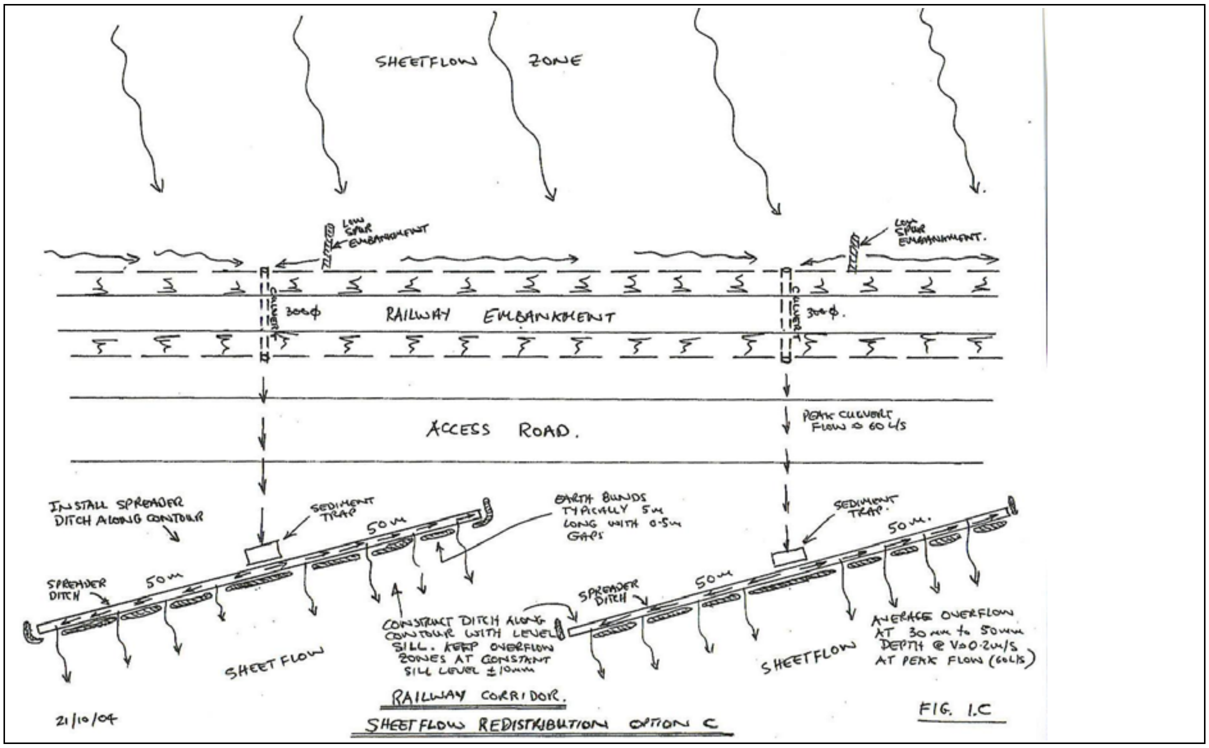
Point Discharge	**Location**						
Plots	**Easting**	**Northing**	**Approx Volume (litres)**	**TDS (g/L)**	**Flow Rate (LPS)**	**Slope (%)**	**Angle of spread**
E20 Levee	787359	7516988	23700	1.43	23	0.55	52
G-IG (load 1)	787486	7516995	26000	1.05	25	0.22	91
G-IG (load 2)			24000	1.46	23		
Steep	788843	7519729	15000	1.05	21	1.75	30
Top Levee	786623	7520828	23000	1.41	23	0.81	41
Top channel	786735	7520731	12000	1.41	21.5	0.55	58

Subsurface flows				
E20 Channel (Day 1)	787312	7516811	10000	1.43
E20 Channel (Day 2)			10000	1.05

Redistribution				
Plots	**Volume (litres)**	**TDS (g/L)**	**Flow Rate (LPS)**	
E20 Levee (initial, see point discharge above)	23700	1.43	23	
E20 Levee (reduced)	11000	1.46		
Top Levee	12800	1.05	14	(Coates pump only)
E20 Channel				
Top channel	12700	1.05	21.5	
Total water used	**180200**			

Moisture sample adjoining E20 Channel	**787312**	**7516811**	**Time since initial channel fill**	**Distance from channel**	**MC% at 200 mm**	**MC% at 300 mm**
Site 1			2hrs	750mm	5.7	
Site 2			2hrs	750mm	5.8	
Site 2			2hrs	750mm	5.8	
Site 1			16hrs	750mm		7.8
Site 1A (Control)			16hrs	4100mm	6.2	7.7
Site 2			16hrs	750mm	5.8	7.8
				Obvious moisture to 700mm from ditch		
Site 3			16hrs	750mm		Wet
Site 1			24 hrs	750mm		Dry
Site 2			24 hrs	900mm	16+	
				Penetration to 900mm from ditch 60mm below surface MC 4.3% 2cm ahead of obvious moisture (colour change) boundary.		
Site 3			24 hrs	750mm	Wet	Wet

Appendix 2: Aquaterra Redistribution Proposals

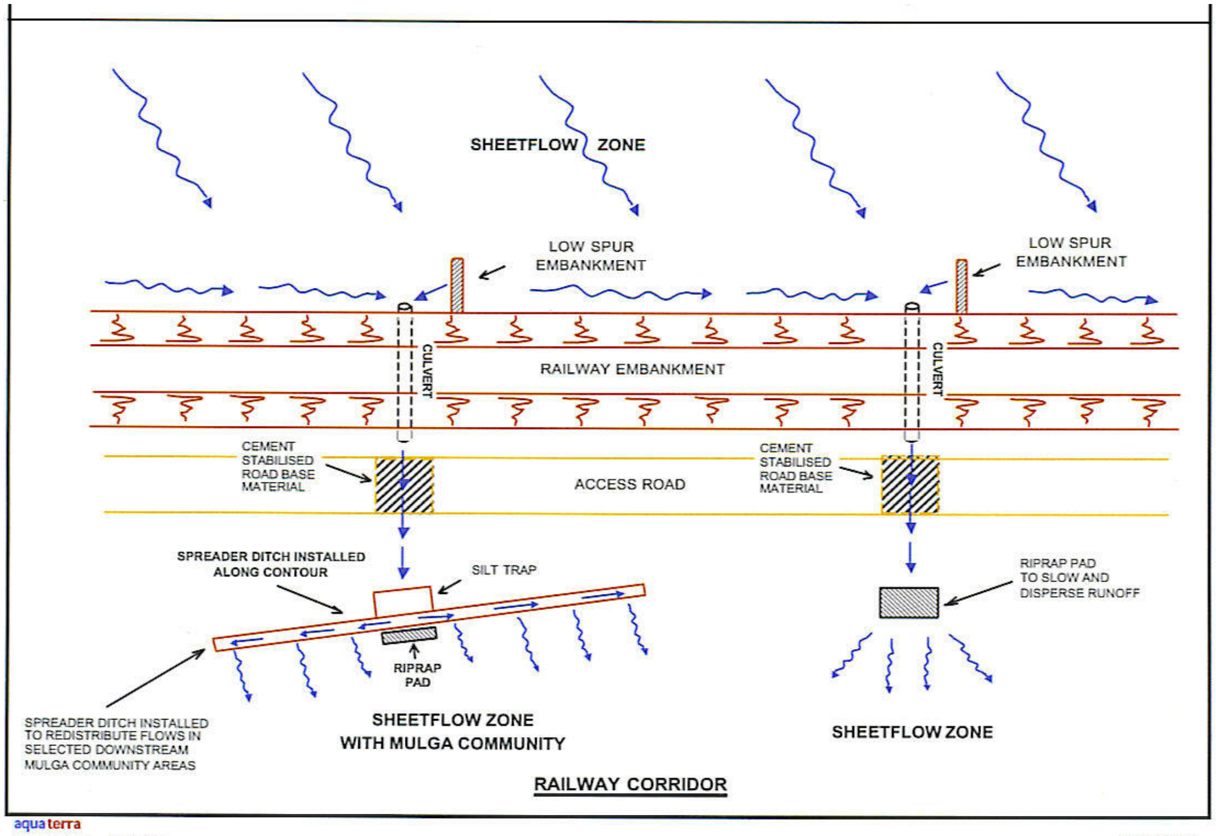


RAILWAY CORRIDOR.

SHEETFLOW REDISTRIBUTION OPTION C

21/10/04

FIG. 1.C



aquaterra

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FIGURE X

SHEETFLOW REDISTRIBUTION

Appendix 3: Plots of Spread from Point Discharge Trials

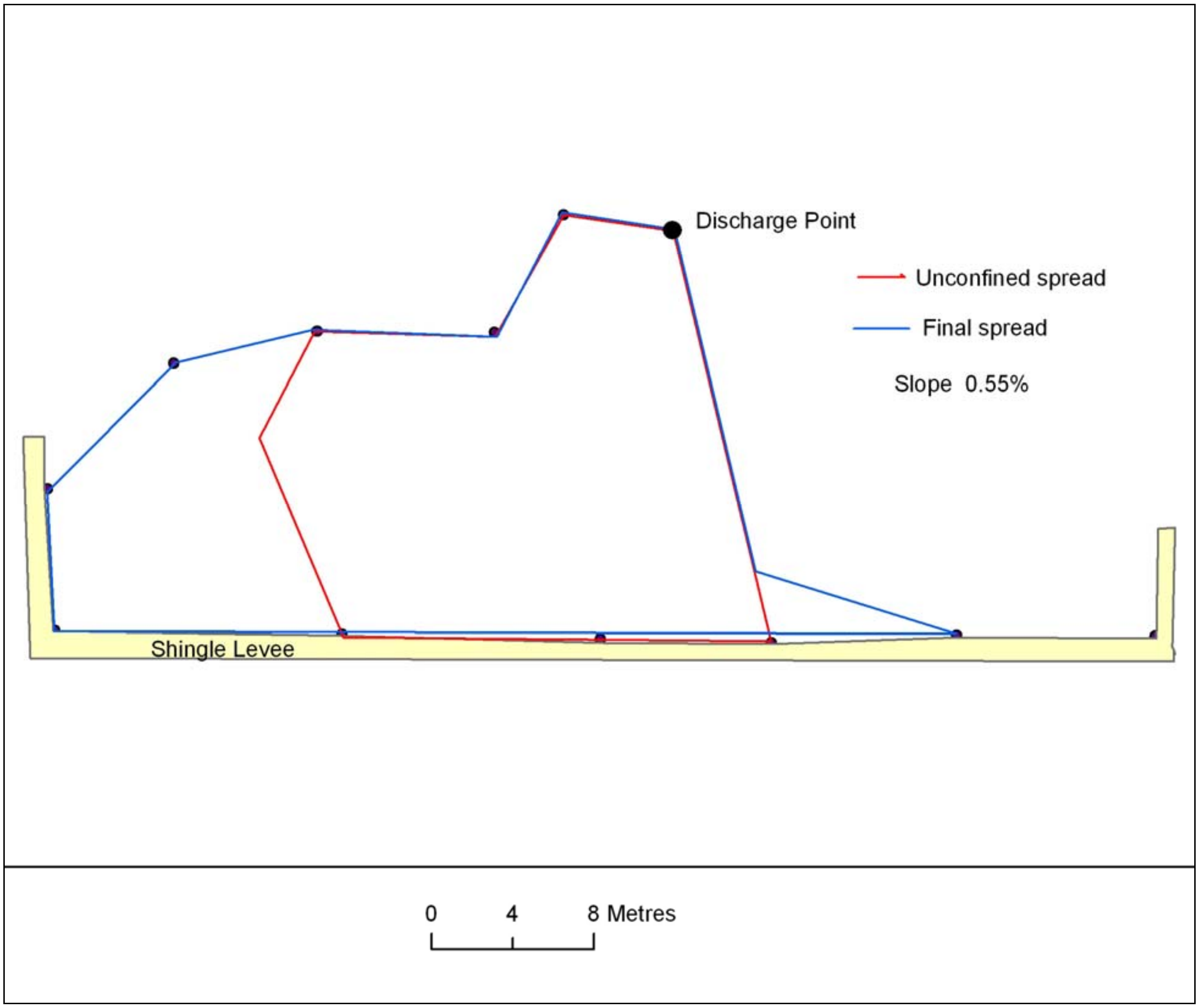

Fig 1: Plot of spread from point discharge, levee south of E20 site. Slope 0.55%

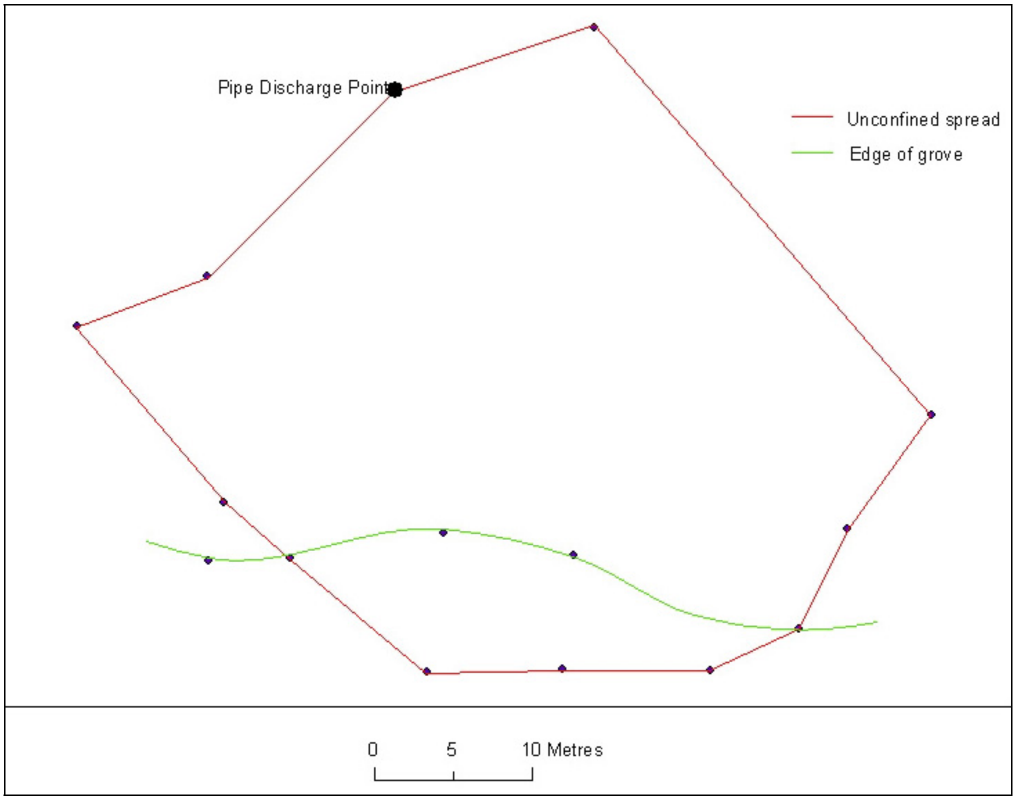

Fig 2a: Plot of spread from point discharge, Grove/Intergrove site. Slope 0.22%

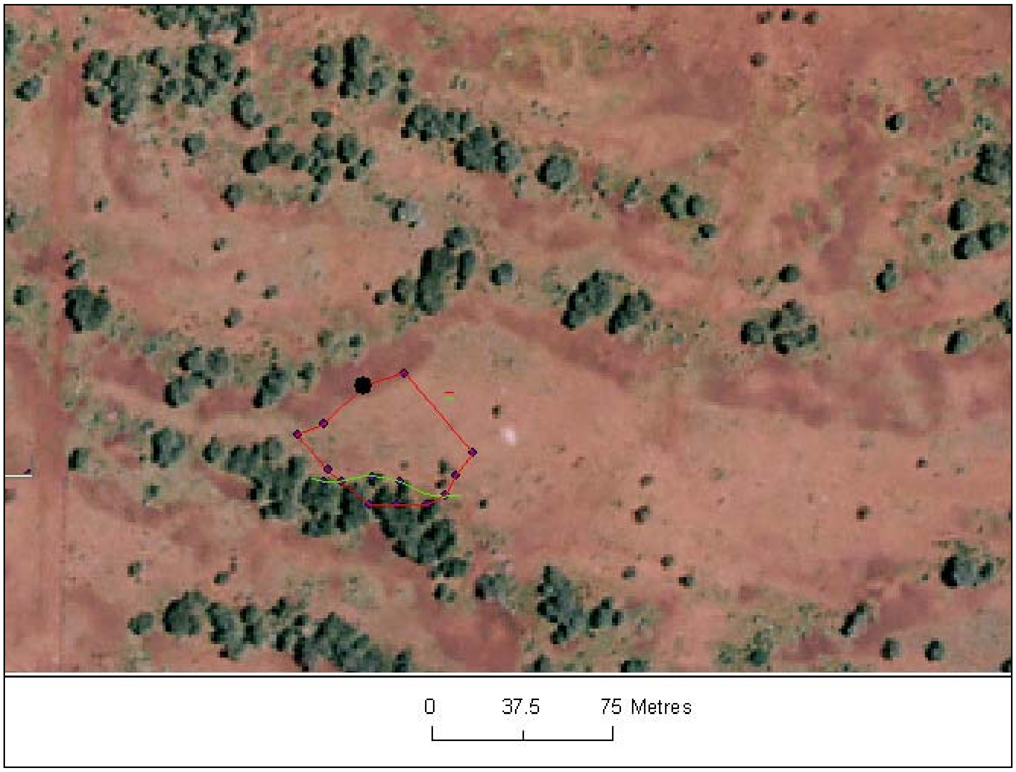

Fig 2b: Grove/Intergrove site showing extent of spread.

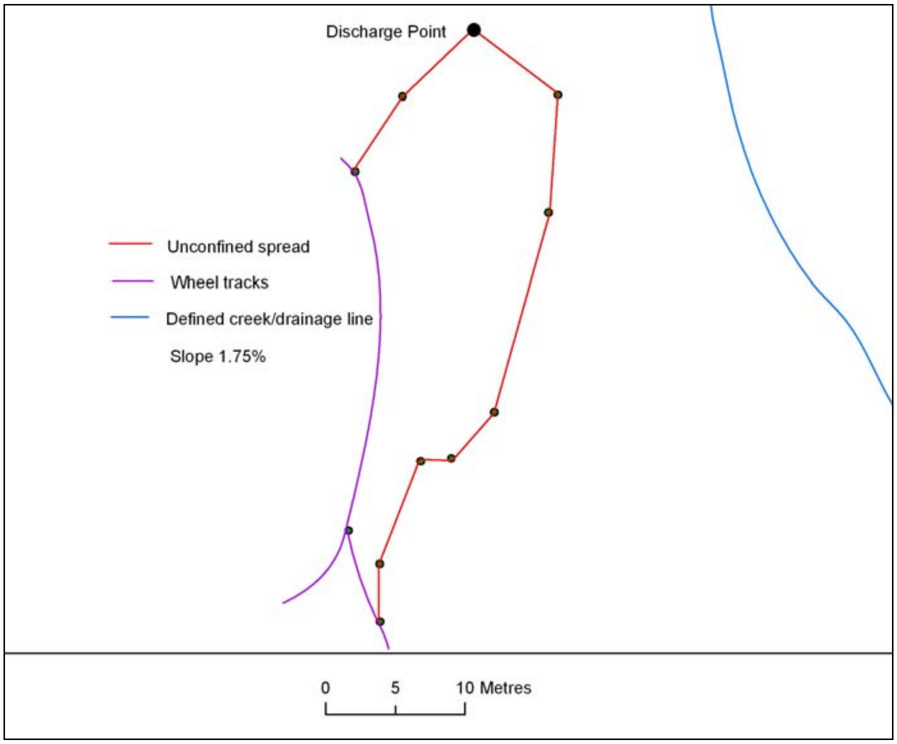

Fig 3: Plot of spread from point discharge, "Steep" site. Slope 1.75%. Spread away from adjacent creek line. Spread to the west affected by wheel tracks.

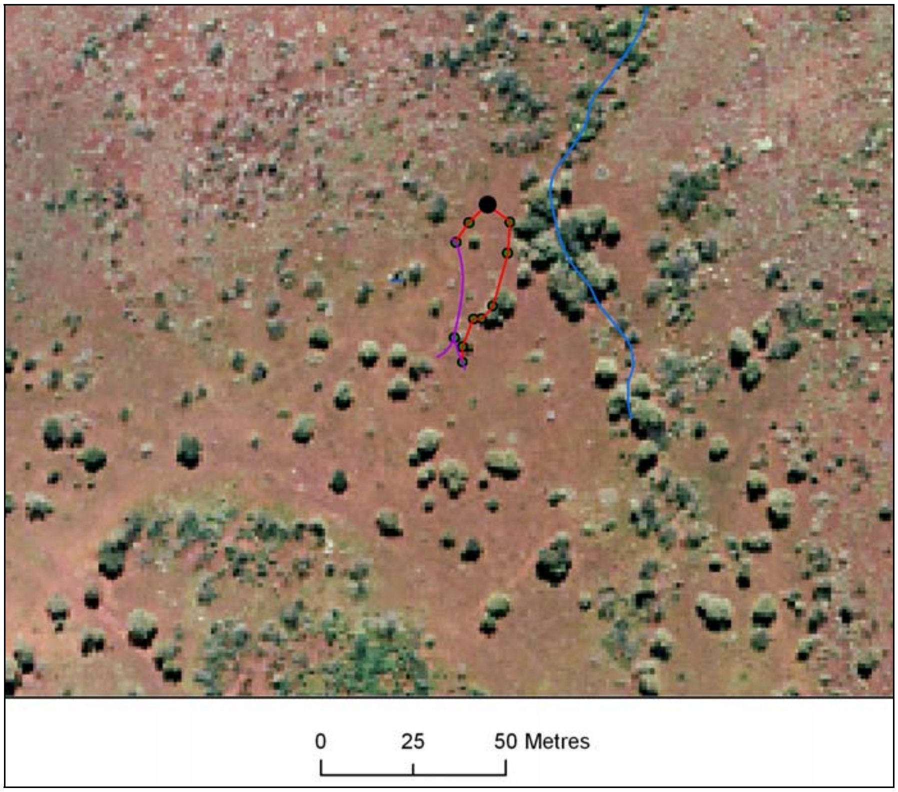

Fig 3b: "Steep" plot in relation to minor creekline. (Photo pre-dates wheel tracks and exploration lines)

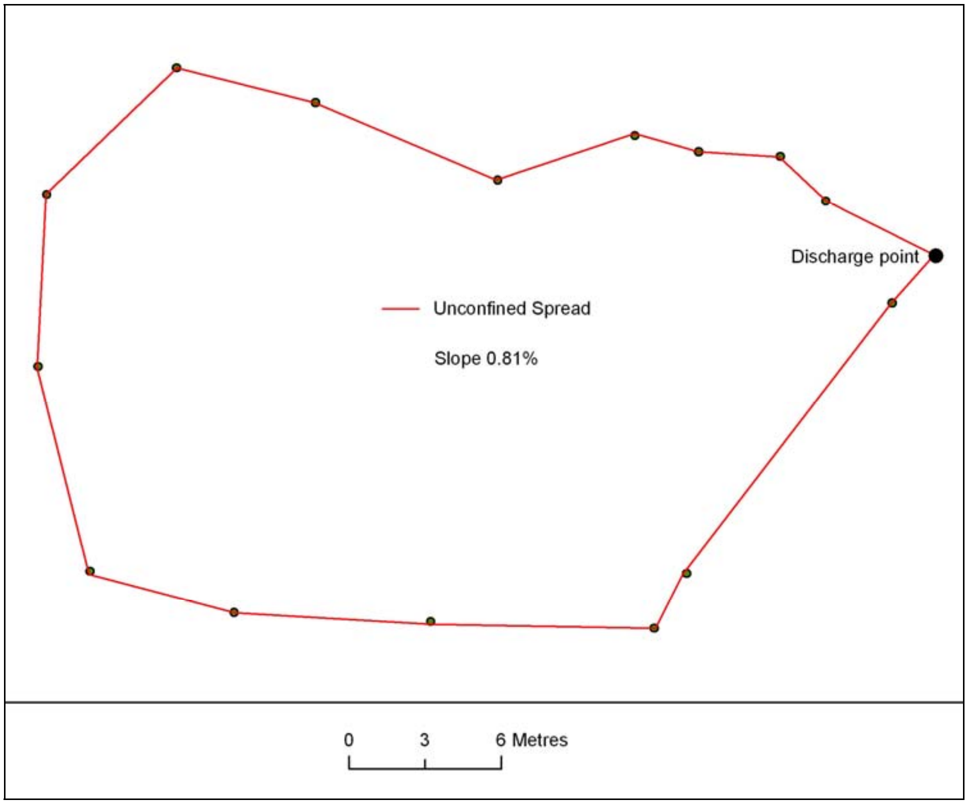

Fig 4: Plot of unconfined spread from point discharge. Below levee along main track. Slope 0.81%

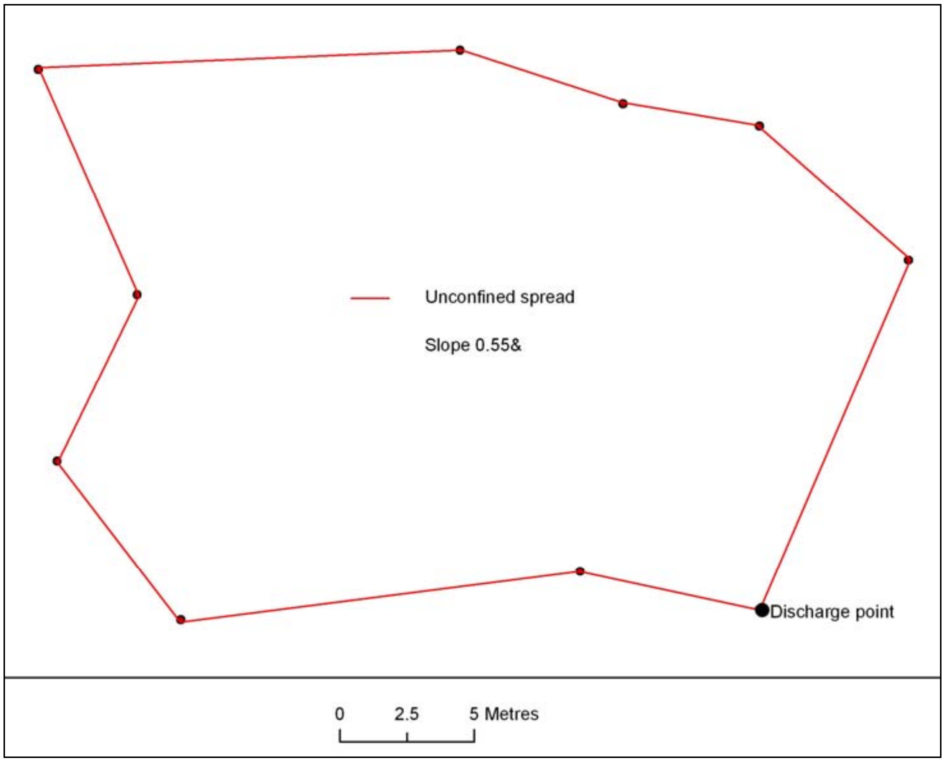

Fig 5: Plot of unconfined spread from point discharge. Below spreader ditch, main track. Slope 0.55%