Management of Surface Water for Controlled Traffic Farming

on slopes up to 2.5%* in the Northern Agricultural Region of Western Australia

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A technical manual from a National Landcare Program Community Support Project led by the Liebe Group.

*The division into slopes below and above 2.5% is based on the observation that once slopes exceed 2.5% it becomes difficult for farm machinery to traverse broad-based roll-over banks. This is a somewhat arbitrary boundary and in reality, the ability to traverse a contour bank depends on a number of issues. Changes in technology may mean that future machinery may be more capable of traversing broad-based roll over banks on slopes greater than 2.5%.
The manual initially outlines the origins of the need for technical information on the ‘Management of surface water for Controlled Traffic farming’ and then explains the processes which effect runoff and erosion in downhill controlled traffic farming systems. Lastly it outlines good management guidelines to manage the risks. The guidelines are related to farming systems and circumstances monitored and measured in the Northern Agricultural Region during 2005–2007, under NLP Project # 043053.

There have been concerns expressed about new cropping systems with controlled traffic or ‘tramline farming’ increasing the risks of water erosion when the new direction of sowing is relatively downhill, compared to sowing ‘on the contour’.

We hope this information will help land managers employing or planning controlled traffic cropping systems reduce the risks of overland flow and soil erosion by water on properties they manage and on neighbouring properties.


Figure 1. Controlled traffic being explained at a field day in the Northern Agricultural Region.

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Introduction: Reasons for development of the manual

The need for this advice arose from the rapid adoption of Controlled Traffic (Tramline) farming in WA, the even more rapid adoption of autosteer for parallel working, and community concern about the removal of overland flow control structures (banks and drains) by some landowners adopting C.T. and autosteer.

- **Rapid adoption of controlled traffic farming and especially autosteer.**

The area of grain growing in WA that was under some form of controlled traffic (from surveys of known adopting farmers), increased from a few trials to 225,000 ha between 1997 and 2004 (Figure 2 below).

This has been mainly driven by:

1. The benefits of reducing inputs costs and driver fatigue in cropping systems in the Northern Agricultural Region (NAR).
2. Soil structural benefits and improved yield from controlled traffic; and
3. The increasing difficulty of employing sufficiently skilled drivers for seeding and harvest operations in WA. Autosteer enables relatively inexperienced drivers to become more reliable because they do not need so much steering skill.

![Figure 2. The changes of farm area under controlled traffic in Western Australia by 2004: Key: 'planned to adopt' = farms planned to be in C.T. by 5 years, 'matched widths' = with matching machinery widths, 'partial C.T.' = with all widths matched and some tracks, 'full C.T.' = all widths and tracks matched. Sustainable Energy Development Office (WA Dept. Energy) report C359M and Blackwell et al. (2004).](image-url)
• **Removal of surface water control structures (banks) to allow easier up and back operations in C.T. or autosteer**

Parallel paths are generally easier to follow by automatic guidance systems; this was especially true for the earlier models of autosteer. This encouraged most growers who adopted autosteer to change the direction of operations of the paddock from ‘race–track’ (round and round) to ‘up–and–back’ parallel to the longest paddock side. Controlled traffic systems without autosteer were also often defined as up and back working. This provided the greatest efficiency by having fewer turns for the whole paddock than ‘racetrack’ operations. Any internal surface water control structures (banks and drains) in a paddock then became obstacles to up–and–back working and growers filled them in to enable parallel working in C.T. (see Figure 3 below).

![Figure 3. Cropping between earthworks without controlled traffic (C.T.); (left). Cropping with C.T. over old earthworks reduced in height; (right).](image)

Most of the adopters of autosteer and controlled traffic were also early adopters of no–till cropping systems and consequently had good stubble retention with improved surface water drainage. Many of these farmers have observed little free water in the drains of the surface water control systems before adopting controlled traffic or autosteer and considered the surface water control systems relatively redundant. Alternatively these observations could also be caused by winter rainfall decline in the NAR after 1999. There was also the attraction of increasing the area cropped in a paddock, thus improving paddock productivity.

• **Neighbour and community concern about the effects of downhill CT or autosteer on run-off, flooding and erosion risk and damage to rural infrastructure**

The original incentive for construction of surface water control structures in parts of the landscape with modest slope (up to 2–3%) was to control run-off better, thus minimising water erosion from paddocks and damage to infrastructure and property from excessive run-off and deposition of soil and debris. Observation of earthwork removal and sowing more downslope than across slope stimulated community and local authority concern that the damaging run-off and erosion would recur. What was not often entirely taken into account with these concerns were the substantial changes in cropping systems which had occurred in the meantime; between the original construction of surface water control systems and the subsequent removal. Before construction most crops were grown with a ‘cultivate–sow’ method or by direct drilling (one pass sowing with full cultivation and disturbance of the topsoil). By the time earthworks were removed on many farms, the crops on those properties were usually sown with ‘No–Till’ methods (narrow points or discs which retained much of the
original plant crowns, old root systems and surface cover) and some with different degrees of controlled traffic. Thus, infiltration behaviour of the soil surface was better conserved by retaining more of the original root and shoot system, as well as minimising the recompaction of soil. However traffic control was rarely complete and soil structure still had problems. There was still the additional risk of cover loss and surface loosening from poor grazing management, as well as loss of cover from poor seasonal growth, thus there were still potential problems of controlling run-off and erosion.

Figure 4. Run−off and erosion from a sloping paddock towards a neighbouring paddock or road, following tillage preceding crop establishment.

- Public meetings identify the need for new technical guidelines and possible need for new surface water control technology.

Such public concern helped to stimulate the support for National Landcare Program funded projects to examine the risks of downhill controlled traffic in both the Northern Agricultural Region of WA, led by the Liebe Group [NLP project # 043053] and the Central Agricultural region, led by the Corrigin Farm Improvement Group.

Public meetings occurred in 2005 and 2006 at Perenjori to discuss the beginnings of the project and the development of this technical manual.

Useful opinion and technical advice was collected from these meetings.

We also consulted researchers in Queensland who had been involved in a similar study of run-off and erosion from downhill controlled traffic systems in earlier years.

NLP project # 043053 was a combined project examining the risks of erosion in downhill C.T. and the possible benefits of very wide rows to reduce drought stress in wheat.
Records of the research and demonstration on very wide rows of cereals to minimise drought stress and the Downhill C.T. project can be found on the Liebe Group website. ([http://www.liebegroup.asn.au/nlpdown.html](http://www.liebegroup.asn.au/nlpdown.html)).

Documents available to be downloaded from the Liebe Group Project website:
Roll-over banks can work! 2006
Ribbon sowing helps wide rows of wheat. 2006
Wide rows, dry seasons and shallow soils. Australian grain article, March 2007.
Controlled traffic farming: it’s all downhill from here!
Management of overland flow in controlled traffic systems in the Northern Agricultural Region of WA.
Managing overland flow in controlled traffic systems in WA.

EXPERIENCE IN QUEENSLAND AND NORTHERN NSW

The first adoption of controlled traffic in Australia was in Queensland and northern NSW. In that environment the changes in erosion control on long low slopes was very noticeable between contour working and up and back controlled traffic (C.T.).

The predominance of very heavy summer rain and cropping clay soils of limited infiltration rate resulted in more frequent occurrence of water run-off and erosion than we commonly experienced in the wheatbelt of Western Australia before 2000; a climate dominated by winter rains of lower intensity and duration, as well as sandier surface soil textures with intrinsically higher infiltration rates. Consequently research and development projects on erosion risk of downhill C.T. were initiated in Queensland in the 1990’s. Some of their findings are helpful in this manual, despite the differences in environment between the two states; especially the experiences with broad-based ‘roll-over’ banks.

Figure 5. Development of gullies from cross-slope working between contour banks in Queensland. *Photo courtesy of the Queensland Department of Natural Resources.*
R&D STRATEGY IN WA AND MANUAL STYLE

As part of a combined project examining the risks of erosion in downhill C.T. and the possible benefits of very wide rows to reduce drought stress in wheat, we worked with limited resources and time to identify the risks. Thus there was a predominant use of observation at monitoring sites using C.T. downhill; complemented by measurements of the key property of maximum infiltration rate with rainfall simulators. Drought years in 2006 and 2007 hampered the investigation; this led to some use of scale models (Figure 6) to demonstrate the principles of downhill C.T. with broad–based ‘roll–over’ banks at shows and field days. (A DVD of the 2006 Perth Royal Show Landcare Exhibit is also available).

Figure 6. The 1/64th scale model of broad–based rollover banks compared to contour banks in action with artificial rain at the Perth Royal Show Landcare exhibit in 2006.

This manual is the combined set of information which we hope can assist growers land managers and engineers to evaluate risks of erosion and damage from excess overland flow when C.T. is employed. We also show the design principles to help use broad–based ‘roll–over’ banks, where appropriate.

As with many collections of technical advice we do not present specific recipes for specific locations. Instead we try and explain the principles behind the processes causing the problem, the guidelines or ‘golden rules’ on which the possible solutions are based. We hope this will help the reader appreciate how these parameters may be applied to their own situation. Once land managers are armed with this understanding they can often implement the appropriate solutions for their landscape and circumstances.
No technical manual of any set of technology is ever complete, without error or beyond improvement. Thus we freely invite constructive comment to improve further versions of this information.

Figure 7. Vehicle damage crossing a bank. (*Wes Baker’s farm, Corrigin.*)

Surface water control structures (banks) can be an obstacle to some farming activities!
RUN-OFF AND EROSION PROCESSES; THEIR EFFECTS, DRIVERS AND MANAGEMENT IN C.T. SYSTEMS

This section describes and explains some of the erosional effects of uncontrolled overland flow; and the processes that drive and influence flow (run-off) generation and erosion. It also examines factors, which when managed, can control these processes in Controlled Traffic systems.

Damage to structures by excess overland flows comes from applying large pressures to one side of a structure, from the water flow and from entrained debris in the flow. The structures can also be weakened by the abrasive forces from water with entrained sediment, as well as by undermining the foundations of a structure. The same volume of water passing under a bridge or culvert over a longer period of time may cause little damage, because the flow depths and subsequent pressures will be less and there may be much less entrained debris. Thus surface water management systems to reduce damage risk often work by delaying the progress of overland flow over the landscape to minimise the size of peak flow, even though the same amount of water may be disposed of and the landscape still has the same overall infiltration capacity through the soil surface.

Figure 8. Damage to a road drain caused by excessive discharge of overland flow from adjacent paddocks following a 200 mm rainfall event over two days (photograph by Jeremy Lemon).
PROCESSES DRIVING SOIL EROSION

Overland flow can cause soil erosion; sheet erosion, gully erosion and deposition.

Sheet erosion

When water flows are relatively shallow and uniform in depth, often at the early stages of run-off during rain, they can be simplistically imagined as thin sheets of water flowing over each other and applying a sliding and pulling force at the soil surface. This layered flow is often called ‘laminar flow’. These forces can detach or pull away soil aggregates and individual particles of silt and sand from the soil surface, as well as plant debris and animal deposits.

When this occurs over a relatively uniform depth and over very wide flows it is called ‘sheet erosion’. Raindrops which penetrate through the flowing sheet of water and apply extra impact and detachment forces to the soil surface can help accelerate the sheet erosion very efficiently. This effect is minimised when the depth of flow becomes greater.

Figure 9. Raindrop impacts into overland flow from ridges and into furrows. The force of the drop impact is being absorbed by the deeper surface water in the furrow, but will be eroding soil in the shallow sheet flow from the adjacent ridge; photograph from a rainfall simulator run.

Rill and gully erosion

When flows become more concentrated and deeper the water movement within the flow becomes less laminar and more chaotic. Then the water is able to apply larger pulling forces to the soil surface, especially from turbulent eddies in the flow and from the impact of large
particles entrained in the flow. Such increased forces can increase the rate of soil erosion along such lines of concentrated and deeper flow; such deeper channels are called rills and their depth encourages further erosion if the soil profile is weak enough. At some point such rills aggregate and develop enough depth to be called gullies. In practical farming terms a gully may be considered to be an erosion channel deep enough to prevent easy passage of farm vehicles.

When the flows slow and spread, often due to reductions of slope and changes of slope shape, the water cannot hold as much of the sediment in suspension, due to the reduced flow rate. This leads to deposition firstly of the largest and then increasingly smaller fractions of the sediment, usually over a wide area, and is often called sheet deposition. Floating components of the eroded mass will continue till they are stranded in shallow depth and around obstacles such as fences, anchored stubble and trees and shrubs.

Costs of such events range from the repair and excavation of damaged structures; such as fences, as well as the costs of any infill of gullies to restore safe access for farming operations. There is also the loss of fertility from soil exported from the paddock since most soil fertility resides in the surface layers and organic matter which are more easily eroded.
Some run-off is very difficult to avoid from extreme rainfall events, especially extra rain upon already soaked land, such as a thunderstorm after a few days of steady rain from a decayed cyclone. Then management choices are about the preferred processes of erosion which can occur, not about the presence or absence of soil erosion from such events where some run-off is inevitable because the soil profile has already been wetted up.

In such circumstances some sheet erosion from relatively uniform overland flow and minimal flow concentration, as well as a stable surface will be preferable because repair costs will be minimal with no gully development. Slow and delayed flows will also help to reduce the size of peak flows and risk to infrastructure; some surface water control structures may be needed to ensure relatively delayed flows through planned disposal routes.

ROLE, EFFECTS AND MANAGEMENT OF SOIL WATER INFILTRATION PROCESSES

Infiltration rate

Run-off from the soil surface can be minimised or eliminated by sufficient infiltration of water into the soil profile through the surface layers. This infiltration rate is driven by the pressure of water at the surface (depth of ponded water) and the volume and connectivity of the macroporosity between the soil surface and the lower layers of the soil profile. Macropores are those large enough (greater than about 60 micron diameter) which can be drained by gravity; smaller pores tend to hold water in them by surface tension and adhesion.

Macropores vary in their shape and origins. The most effective for water movement are fissures (cracks) and channels. Cracks are more common in clay soils, especially swelling and shrinking clays but such textures are relatively rare for top soils in most parts of the northern agricultural region. Therefore channels or biopores are more often the major functioning macropores influencing infiltration rate into WA topsoils in the wheatbelt.

In sands the main macropores are in the spaces between the sand grains, according to the packing or geometric organisation of the sand grains to each other. These macropores are ‘vughs’ or packing macropores and can also be large enough to conduct water if they are interconnected. The sandier the topsoil is the more packing macropores there can be between the larger grains of sand; thus sandy soils generally drain more easily than soils with more clay.

Soil aggregates also form packing macropores between them to aid profile drainage in more stabilised soil conditions. Dead plant root systems can also act as drainage pathways from the surface when the plant crown and stem bases are intact. The water is drawn along the dead roots and the channels they occupy in a preferred pathway, like a wick draws oil to a flame.

Role of soil cover

If only macropores, dead root systems, sand content and soil aggregates controlled infiltration into our cropping soils, then management would be relatively simple. Unfortunately the raindrop impact process induces surface changes to our soils which can be very counter–productive to infiltration.

The impact of a falling raindrop on a wet soil disrupts the particles and aggregates and suspends fine particles in the surface water. The physical impact can also act like a hammer
on the soil surface and pack very thin shallow layers (crusts), especially of sands with a wide range of sizes, these compacted layers can be very thin, but very effective in reducing infiltration. When the suspended and dispersed soil particles in the infiltrating water also block and fill the remaining macropores, the infiltration rate through the soil surface can be reduced further, creating a hardsetting surface.

It is also important to be aware of the role of water repellency in run-off from dry soils. This may have an impact effective irrespective of the amount of soil cover.

Thus management and protection of surface condition is very important to maintain sufficient infiltration rates to reduce run-off and erosion risk.

Organic material from plants, especially detached leaves and stems laying on the soil surface, protect the surface soil from direct impact of rain and allows pathways of flow underneath them into the soil profile (see Figure 12). When the crop residues and pasture litter are decomposed, it can help ‘glue’ soil into more stable soil aggregates and the risk of collapse of surface soil and formation of crusts under rainfall is reduced.

Soil organic material also plays a key role in assisting infiltration of water from the soil surface into the soil profile. Soil organic matter can improve soil resilience and resistance to compaction forces. The fibres from dead root systems and fungal hyphae, as well as the more ‘sticky’ components of soil organic matter can help to provide internal strength to the soil matrix, increase the shear and compressive strength of soil and minimise the loss of transmission macropores and pore continuity by external forces from traffic and livestock, as well as internal forces from soil drying. Vertical macropores, at least in clay subsoils, are also more stable and able to resist compressive forces from the surface than packing pores or fissures, because the compressed soil around the channel helps to increase the strength under loading from the surface (Blackwell et al. 1990).

A special example of dead plant roots and crowns assisting surface drainage from water repellent sand was found by rainfall simulator measurements at the Corrigin Farm Improvement Group downhill research site in 2007 (see Figure 13). Maximum infiltration under storm rain of about 100 mm/h was greater when canola stubble was preserved; the bypass flow alongside the canola roots (in the space formed by root shrinkage after death
and drying) enabled flow rates of up to 40 mm/h into the soil profile. This encourages the use of canola as a crop after burning cereal stubble; it will help reduce risk of run-off during summer storms on water repellent sands. However, rolling or slashing the canola stubble after harvest will uproot much of the dead canola ‘stumps’ and the by-pass flow for good infiltration may be lost.

![Image](image-url)

Figure 13. The rainfall simulator at the Corrigin Farm Improvement Group downhill site.

**Effect of stock grazing**

Grazing can reduce infiltration considerably and encourage soil erosion by soil surface loosening. Retention of sufficient cover relies on removing stock at critical cover levels and surface conditions, e.g. 70 per cent attached cover. Stock tracks can also encourage flow concentrations when they cross rows and furrows from a previous crop. Watering points, stock camping zones and gateways will become the most erosion prone areas if stock trampling and grazing continues sufficiently in such areas in dry conditions.

Rotational grazing or crash grazing may encourage more pasture root growth compared to set–stocking, thus developing more channels to assist surface water drainage. The stock are also in the paddock for relatively short periods, compared to ‘set stock’ grazing; thus surface compaction by stock treading is reduced. These effects are more evident when stock are prevented from grazing pasture on heavier textured soil in wet conditions (Proffitt *et al.* 1995). Compaction from stock hooves in wet conditions results in reduced infiltration and increased run-off (Coles and Moore, 1998).
Effect of flow direction along furrows

Entrainment of soil particles and aggregates into overland flow across the soil surface is considerably dependent of the speed of flow; the slope of the surface and the roughness of the surface. Most current crop establishment systems form furrows of various sizes and shapes. Furrows are very effective at gathering, collecting and guiding surface water flows.

In most situations on low slopes, furrow direction will control the direction of overland flow, rather than the overall slope direction of the land surface. When the furrow slope is not constant in one direction, reversal of slope can induce flow accumulation and overflow of furrows into the adjacent downhill furrow; this induces a flow concentration as in Figure 15. This tends to be less effective when protective cover and/or soil stability is lost and ridges are levelled and furrows filled.
Bare soil areas

Tramlines, turning headlands and inter−rows

Relatively small areas of a paddock being cropped can have little cover in a C.T. system in low rainfall areas. These areas can be:

1. The tramlines or wheel−ways if they are not sown or have very little crop establishment. Some growers chose to leave bare, unsown tramlines to gain maximum benefit of soil firmness which reduces rolling resistance and fuel costs. Loose stubble on bare tramlines can form ‘microbanks’ to divert surface flows on the tramlines laterally into the adjacent soil of higher infiltration rate (see Figure 16). Other growers chose to sow the tramlines, even with minimum disturbance disc seeders; especially to help control grass weeds in cereal crops. The low levels of competition for water and nutrients in bare tramlines allows more easy colonisation and development of grass weeds; such weeds are out competed by the growing crop in the zones between the tramlines.

![Figure 16. bare tramline showing evidence of flow diversions away from the tramline by ephemeral mini−dams of detached stubble.](image)

2. Unsown parts of the headlands that may have been omitted for convenience of operations (e.g. using ‘Clapper corners’ Webb et al. 2004; page 64).

3. Wide (approximately 500 mm or more) inter−rows from wide row sowing to reduce drought stress in low rainfall zones (Blackwell 2007). This method uses the soil moisture stored between the wide inter-row to supply water to a crop during periods of little rainfall and high evaporative demand to reduce crop drought stress.

These relatively bare areas can encourage run-off during periods of intense rainfall. In some circumstances the flow can be intercepted by adjacent areas of good infiltration rate. In other circumstances these small excess flows may initiate flow concentrations in a paddock and cause problematic erosion features.
**Turning headlands**

Turning headlands in C.T. experience more traffic than the rest of the paddock between the tramlines. This results in more widespread soil compaction, especially a headland which is more convenient for loading seed and fertiliser and unloading grain. Therefore there is more risk of run-off (see Figure 17).

![Figure 17. Gully erosion on sloping headlands in a C.T. paddock.](image)

**Large areas of low permeability soil within and adjacent to the paddock**

In the NAR eastern areas some landscapes have zones of poor permeability high in the landscape and on the upper slopes of broad valleys. These zones are often gravel deposits with high clay content or red loamy sediments with very low porosity. Water shedding from such impermeable zones can accumulate and concentrate in flows over the rest of the paddock to cause severe erosion in extreme cases (see Figure 18).

Other hard areas outside a paddock may also create run-off easily and that flow may come onto the paddock as run-on.
SUMMARY OF EFFECTS, DRIVERS AND MANAGEMENT OF RUN-OFF EROSION IN C.T. SYSTEMS

Erosion processes in C.T. paddocks are driven by run-off from soil surfaces with low permeability (or infiltration capacity) to rain.

Low permeability areas within and upslope of a paddock can initiate problem run-off and erosion.

Flow concentrations within the paddock are the main cause of gully formation.

Good surface condition and good soil structure will maintain high permeability and help minimise run-off.

Good management of grazing to maintain good cover can minimise the run-off and erosion risk on grazed paddocks.

Parallel downhill furrows and tramlines with low slope can maintain flow separation if the soil surface is stable enough.

Even the best soil and surface conditions for infiltration can generate run-off if the soil is already very wet from previous rain.
RISK MANAGEMENT—STRATEGY (AND PLANNING) GUIDELINES

Management decisions and systems of operating crop and livestock operations can influence run-off behaviour, particularly the infiltration rate of the soil. This section of the manual explains and identifies general guidelines for erosion risk reduction. The guidelines can be very different for C.T. systems with or without livestock in the Northern Agricultural Region; thus the latter part of this section translates the guidelines into general strategies for each farming system.

The risks of overland flow and erosion problems in downhill controlled traffic on low slopes (less than 2.5%) in the NAR are mainly determined by:

- rainfall characteristics which can generate run-off; and
- maximum infiltration rate of the rainfall into the soil, including surface features in and adjacent to the paddock which influence run-off directions.

Rainfall characteristics

In general, the rainfall events with high risk of generating damaging run-off and erosion fall into two categories:

1. Intense summer and early autumn storms; and
2. Rain-bearing depressions from decayed tropical cyclones (e.g. Cyclone Vance in 1999).

Management strategies and tactics to minimise overland flow and erosion problems in C.T. need to accommodate both kinds of high risk rainfall events.

The storms will usually be of a duration of less than a day, while the decayed cyclones can persist for more than a day; the erosivity of both are highly dependent on preceding rainfall which may have pre-wet or saturated the soil profile, and restricted the capacity of the soil to accept more water.

Projected changes in climate and rainfall patterns for the NAR will increase the likelihood of summer rainfall events of the storm and decayed cyclone type. This increases the value and urgency of developing overland flow control strategies in controlled traffic systems established or planned in the Northern Agricultural Region.

Figure 9. A simplified rainfall graph contrasting patterns of storm rain events with decayed cyclonic rain events in the Northern Agricultural Region.
Infiltration rate

It is important to recognise that cropping direction is not the main influence on the infiltration of rainfall into soil in a paddock. The surface conditions and soil structure, control most of the infiltration therefore have most influence on run-off. Figures 20 and 21 illustrate this by contrasting three different farming systems, and highlight the differences when soils are unsaturated or saturated.

Unsaturated soil

Figure 20. Contrasting farming systems and the influence on run-off from rainfall; rain onto unsaturated soil (arrow size indicates the relative rate of run-off or infiltration).

Saturated soil

Figure 21. Contrasting farming systems and the influence on run-off from rainfall; rain onto saturated soil (arrow size indicates the relative rate of run-off or infiltration).
The following are GUIDELINES to reduce risks of overland flow and erosion for controlled traffic farming in the Northern Agricultural Region fall into four broad categories:

- Improving and maintaining infiltration (A)
- Minimising flow concentration (B)
- Slowing flow rates and (C)
- Diverting flows (D)

These strategies need to be considered within a good overall plan for a farm and its neighbours in the same local catchment area.

A. Guidelines for improving and maintaining infiltration

(i) Maintaining infiltration by good soil structure with traffic, tillage, grazing, macropore and soil organic matter management.

Suitable strategies to manage good structure in the surface soil and in the rest of the soil profile, in a controlled traffic cropping system are:

I. Traffic management

Traffic management helps to minimise the amount of soil compaction from crop production operations. Soil compaction can damage soil structure and restrict infiltration of rainfall into the soil profile by closing macropores; see section ‘role and processes of infiltration’ p. 10.

Controlled traffic systems vary in their degree of wheel matching and the discipline applied to general traffic management in the paddock (see Figure 23). Many current systems do not include harvest traffic control; the header wheels and chaser bin wheels do not match the traffic pattern. The chaser bin also has to be on the tramlines when it is loaded from the header in a well matched system. The few farms in WA which are fully matched through to harvest traffic have much greater capacity to improve and control soil structure between the tramlines.

Figure 23. Partly matched C.T. system (left); fully matched C.T. system (right).
Even a well matched system can develop compaction between the tramlines from occasional traffic when entering and leaving the paddock. Some degree of discipline is required to minimise compaction from occasional vehicle movements.

II. Tillage management

Residual compaction between tramlines may require early ameliorative deeper tillage, even deeper working of seeding points, to remove the limitations to infiltration from shallower soil compaction.

Turning headlands tend to be an exception for deeper tillage, because loose headlands can restrict trafficability and vehicle floatation, especially in wet conditions. Thus turning headlands may require separate management of overland flow risk; see the later section (p. 30) on run-on control.

Traffic and tillage management guidelines for improving and maintaining soil structure to maximise infiltration in controlled traffic and minimise run-off are:

1. Develop a controlled traffic system that accommodates all traffic from cropping operations, including harvest, and ensuring that machinery design allows chaser bins to be unloaded on adjacent tramlines to the harvester.
2. Ensure operational practices that avoid undisciplined traffic.
3. On turning headlands with some cross slope, consider some strategically placed broad-based rollover banks to divert overland flows to safe disposal zones.
4. Incorporate a plan to loosen residual surface compaction, by separate tillage or deeper working at seeding between the tramlines.

III. Grazing management

Suitable strategies to manage soil structure by grazing management involve minimising the periods of grazing in wet conditions and maximising the use of crash or rotational grazing. Consequently, conservative management of cover to levels above 70 per cent, ‘crash’ or rotational grazing and minimal grazing in wet conditions may help maintain soil in a more optimal condition for infiltration of heavy rains.

Absence of livestock on a downhill C.T. paddock will avoid the soil structure problems caused by grazing animals. If livestock is kept on dedicated parts of the farm managed for grazing, or feedlots of some suitable design, fodder may still be produced from the C.T. paddock by hay production or separation of small grain and chaff from a harvested crop.

Figure 23. Contrasting good grazing management (above) and poor grazing management (left).
Grazing management guidelines for improving and maintaining soil structure to maximise infiltration in controlled traffic and minimise run-off are:

1. Minimal grazing in wet conditions.
2. Rotational grazing or crash grazing.
3. Consider no livestock on specific paddocks or the whole farm.

IV. Soil macropore and organic matter management

Suitable strategies to manage soil structure by soil macropore and organic matter management involve minimising tillage to conserve as much as possible of the previous root systems. A complementary minimum removal of crop residues will also assist increase of soil organic matter as those residues decay and increase soil organic matter levels.

If the only tillage is for crop establishment, i.e. a No Till system, the effect on soil fauna and organic matter conservation is greater when row spacing of the seeding equipment is relatively wide (e.g. 300 mm) and the points or discs have a narrow disturbance width. This allows more organic matter and macropores and macrofauna to be preserved in the inter-row zone to assist infiltration of water into the soil; principally ants and termites in the lower rainfall areas of the Northern Agricultural Region.

Soil macropore and organic matter management guidelines for improving and maintaining soil structure to maximise infiltration in controlled traffic and minimise run-off are:

1. As little tillage as possible — No Till system.
2. As much stubble retention as possible.
3. As wide row spacing of crops as possible.

(ii) Maintaining infiltration by good soil cover with grazing and crop residue management

I. Grazing management

Suitable strategies to manage soil cover by grazing management are as above in the section on managing soil structure; a minimum visible ground cover of 70 per cent is a good guideline. Otherwise grazing animals will remove too much of the vegetation and, combined with the surface disturbance from treading, increase the opportunities for restricting infiltration through the soil surface; see section III (p. 20).

Grazing management guidelines for improving and maintaining soil cover to maximise infiltration in controlled traffic and minimise run-off are:

1. Minimal grazing in wet conditions.
2. Rotational grazing or crash grazing.
3. Consider no livestock on specific paddocks or the whole farm.
II. Crop residue management

Suitable strategies to conserve plant crowns root systems and associated cover involve both the conservation of the residues post-harvest and maintaining the location of root crowns within the soil surface. Residual root systems and plant crowns, as well as attached and detached plant material, assist infiltration through soil surface protection and preferential pathways alongside dead roots and through macropores.

These valuable residues can be lost or lose their beneficial effects by:

a. Burning off during the autumn.
b. Cultivating the soil, thus burying the surface residue and disrupting the remnant root systems.
c. Shallow ‘tickling’ the soil with chain or light harrows or even rolling or slashing the stubble post harvest.

This can dislodge the root crowns of more woody crops, such as canola, and reduce the opportunity for bypass flow.

Burning is often employed to reduce the amount of weed seeds before the next crop. Burning windrows of crop residue can help minimise the area of paddock losing cover, but still loses residue which could have been spread over more of the paddock. A realistic alternative in controlled traffic systems, beginning to be adopted in WA, is the disposal of chaff and associated weed seeds on the tramlines; Furry or chaffy tramlines (Figure 26 and Webb et al. 2004). There the weed seeds may decay, be harvested by ants or, if they germinate, be controlled by band spraying.

Figure 26. A chaffy tramline soon after harvest, chaff diverters have concentrated the chaff and weed seeds on each tramline, while the straw is spread over the full width of harvesting.
Crop residue management guidelines for improving and maintaining soil cover to maximise infiltration in controlled traffic and minimise run-off are:

1. As little tillage as possible; including shallow harrowing and rolling of some crop stubbles.
2. As much stubble retention as possible; especially canola on burned wheat stubble.
3. As little burning as possible.
4. Disposal of crop chaff and weed seeds on tramlines instead of burning.

B. Guidelines for minimising flow concentrations

(i) Encouraging flow separation

I. Minimise reverse grades in contour working

Reverse grades cause opposite slope directions on sections of furrows, tramlines or tracks, and concentrate flow from opposite directions. This flow concentration fills and overflows the furrow, or tramline edge, leading to water movement directly downslope. Flow velocity and depth are increased as water moves further down the slope, creating rills, then gullies (see Figures 27 and 28).
Figure 28. A paddock worked on the contour showing the possible effects of reverse grades, leading to run-off concentration and gully initiation (from Carey, 2007).

Controlled traffic has been defined as having tramlines that provide ‘positive drainage of surface water to a safe disposal point such as a contour bank or waterway’ (Tullberg et al. 2000). This implies that all the run-off generated within a controlled traffic furrow or wheel track is retained in the furrow or wheel track with no cross flows. Furrows and wheel tracks directly up and down the slope as in Figure 29 will comply with this definition as they only have to accommodate the rainfall that falls in them.

II. Use parallel sowing with a simple slope

Maintaining consistent downhill workings with low slope will encourage flows to keep separated within their own flow path in a furrow, tramline of track; this will minimise the risk of flow concentrations and development of deep rills and gullies; a simple example is shown in Figure 29 below.

Parallel sowing in furrows has been observed to maintain flow separation on slopes of 2 per cent or less at the monitoring sites in the NAR between 2005 and 2007; an example of this is shown in Figure 30.

Figures 31 and 32 illustrate how a complex slope shape with a C.T. system either parallel to, or angled away from a waterway, can increase erosion risk.

Figure 31 offers fewer zones where reverse grades can occur in tramlines and furrows, thus less risk of development of gullies in parts of the paddock.
The overland flow paths suggested in Figures 31 and 32 are most likely when the ridges between the furrows and tramlines are relatively unstable and the amount of anchored crop residue is low.
Figure 31. Situations where gullying may occur in a C.T. layout parallel to a waterway (from Carey, 2007).

Figure 32. Situations where gullying may occur in a C.T. layout angled away from the waterway (from Carey, 2007).
Integrity of the ridges between the furrows is important; especially if the sowing direction is not parallel to the main slope. Ridges can collapse if the soil structure is poor and even for good soil structure, if the anchorage of the soil by roots and crowns of the previous crop is poor. This is illustrated by soil surface collapse and induced sheet erosion at one of the observation sites in the NAR study (see Figure 33 below).

Crop management systems which maintain soil cover and encourage accumulation of soil organic matter will help minimise the risk of ridge collapse and loss of furrow integrity. Absence of livestock will also be essential to minimise such risk.

Figure 33. Evidence of ridge instability and low levels of crop residue, leading to failure of a downhill C.T. system to maintain overland flow separation during run-off from an early autumn storm.

III. Try extra directions in a paddock with complex slopes

Few paddocks in the Northern Agricultural Region have a nice flat surface and only one slope. There are often changes in general slope direction and concavity or convexity in the general slope shape; especially on land systems which have broad valleys between ranges of low hills.

A single direction of working by controlled traffic may be suitable for one section of a paddock, but less suitable for another. Concavity may be the biggest challenge in choosing a single direction. Having two directions which both match the needs for parallel surface flow and low slope of furrow may help to reduce the risk of flow concentrations from reverse slopes in the centre of the concave zone; as in Figure 34 below.
Care is needed at the join between the zones with different directions; too much general traffic in this zone may increase compaction, reduce cover and induce unwanted run-off and flow concentrations to develop gullies.

Figure 34. A C.T. layout that could be used to accommodate different slope directions in a paddock (from Carey 2007).
IV. Control livestock tracks

This is not easy; a practical suggestion may be the location of troughs and feeding points at the bottom of slopes so that the length of flow path along any livestock track is minimal before the water is disposed into the down-slope headland. This may avoid flow concentrations at the upper part of the slope which can then initiate rills and gullies which can continue down the rest of the paddock. Movable watering points may also minimise track development (see Figure 35 below).

![Figure 35. Sheep forming numerous tracks grazing cereal stubble.](image)

**Sowing direction and livestock management guidelines for maintaining flow separation of run-off are:**

1. Sow downhill at maximum 2.5% slope; carefully incorporate plans for broad-based rollover banks in the system.
2. Consider changing sowing directions in different parts of the paddock for more complex slopes.
3. Conserve stubble and soil structure to maximise furrow and ridge stability.
4. Consider using movable watering points or locate them at the bottom of the slope.
(ii) **Minimising run–on to the paddock**

A paddock in controlled traffic and well managed for erosion risk within the paddock can still be at severe risk of erosion development if the opportunities for run–on to the paddock are not well managed. For convenience here, the turning headlands are considered to be external to the main paddock, even though they are within the paddock boundaries.

A good example of erosion damage to a C.T. paddock from run–on, otherwise well managed in downhill operations, is shown in Figure 36. The run–on causing gully development came from and upslope rocky area in native vegetation.

The run-off in Figure 37 came from a rocky hill. In both cases an interception bank and perhaps diversion of flow to a storage dam, would have reduced the risk of gullying in the paddock from such run–on. Fencing the rocky area to encourage revegetation should also help reduce run–on.

![Figure 36. Gullyng down to the clay B horizon by run–on to a Controlled Traffic paddock following a tramline with low slope [picture J. Lemon].](image)

![Figure 37. A paddock in C.T. with low surface cover on a livestock–free farm following a low rainfall year. Erosion of tramlines has occurred from concentrated run–on from a rocky hill and turning headland behind the photographer.](image)
Turning headlands in C.T. paddocks will usually be more compact than the rest of the paddock and encourage some run-off (Figure 37). When this run-off is on the upslope side of a paddock there is more risk of that becoming ‘run–on’ to the rest of the paddock and initiating gullies by flow concentration. Thus turning headlands on hill tops or tops of ridges present such risk and may be avoided by adjusting paddock boundaries to ensure tops of hills and ridges are sown over before the cropping traffic arrives at the turning headland.

### Paddock layout guidelines for minimising run–on are:

1. **Ensure flows from rocky hills upslope of the paddock are safely captured or diverted.**
2. **Sow over hill tops and avoid turning headlands along ridges.**
3. **Beware of run-off from turning headlands and tracks adjacent to the paddock and perhaps use diversion drains to safe locations.**

(iii) **Management of impermeable zones within the paddock**

These zones are like a special case of run–on from outside the paddock, but occur within it; see Figure 38 below.

The geological material the soil is forming from may be so dense, e.g. some clay and gravel deposits or shallow rock, that whatever management methods are applied it will always have a low infiltration rate for rain. The most logical management for such zones may be to isolate and collect the problem run-off with suitable customised earthworks and lead it safely to a suitable disposal point. There may also be an economically viable curative treatment; e.g. deep ripping and gypsum.

Figure 38. An example of gullying caused by run-off from a **low permeability part** of a paddock. (*Redder coloured zone in the distance.*)
Paddock layout guidelines for minimising problems of low permeability areas are:

1. Clearly identify the location and size of such zones.
2. Seek advice on the economic viability of curative treatment.
3. Consider constructing suitable customised earthworks and lead run-off safely to a suitable disposal point.

C. Guidelines for slowing flow rates

I. Changing furrow slope

When the slope is more than 2.5 per cent, parallel to the longest fence, it may be possible to change the angle of sowing to keep the furrow slope less than 2.5 per cent. Figure 39 shows how the soil loss by water erosion changes with slope of the furrow. So erosion risk on a 5 per cent slope can be reduced by 70 per cent by changing the furrow direction to reduce furrow slope to 2 per cent.

This analysis was done for clay soils in Queensland (Water Erosion Prediction Project WEPP). We expect the relationship to be in similar proportions for other soil types and climates, depending on the stability of surface soil to maintain ridge and furrow configurations.

Care may be needed in choosing the operating sequence when sowing on a direction not parallel to the longest fence; turning downhill may produce a safer furrow pattern for minimising flow concentrations than turning uphill.

Figure 39. Estimated soil erosion rates from downhill run-off along furrows with different slopes and under a No-Till or a cultivated cropping system for a vertisol in Queensland (data from G. Titmarsh, Queensland DNR).
II. Soil cover and surface roughness

Water flows downhill more easily over smooth surfaces than rough ones. Over smooth surfaces the flow rate can accelerate to faster speeds with more energy to entrain surface soil and debris; to erode rills into deeper and wider forms such as gullies. A rough surface, from surface stones, surface hollows and rises, attached stubble and pasture expends some of the energy in the flowing water as the flow is obliged to move around and over the ‘obstacles’ in the rough surface.

A guideline of a minimum of approximately 70 per cent attached stubble, pasture and stone is often used to minimise erosion by maintaining sufficient surface roughness.

Processes which tend to reduce such cover levels are:

Grazing—(especially by set stocking). Grazing in dry seasons has an additional problem from surface disturbance by trampling in dry conditions, which loosens the surface soil to make it more erodible. Good grazing management and possibly rotational grazing will minimise this risk; as for cover level management for maintaining infiltration rate.

Poor crop growth and a rotation phase with poor cover levels; e.g. lupins and canola, even in a grazing–free regime. Crop rotations minimising the use of lupins and canola in dry seasons will help reduce this risk.

Termite consumption—(surface stubble, on red loams, in the NAR). Detached and anchored stubble from wheat crops has been observed to be enclosed by termite ‘tunnels’ and is consumed during summer. This is rarely seen on sandy soils, presumably related to the amount of clay available to build the ‘tunnels’. There seem to be few management choices available to minimise the problem and there will be associated benefits for infiltration rate from the macropores formed by the vertical burrows.

Burning—(of crop stubble). Soil surfaces which lose stubble from burning will be less rough and therefore encourage faster overland flow. The same management guidelines as for cover management for good infiltration are appropriate.

III. Filter strips

Filter strips are zones in the paddock across the slope direction which slow and disperse overland flow by having more attached stubble and forming ‘dams’ from captured flotsam; often detached stubble. They have been regularly employed in floodplain management in Eastern Australia and may have a role in rain–fed crop production with controlled traffic.

Figure 40 shows a diagram of how a concentrated flow can be dispersed by an array of anchored stems in a filter strip. Figure 41 shows an example of a filter strip working in Queensland. The same effects of detached stubble in flotsam of overland flow forming mini dams can be seen in many WA farming situations (see Figure 42).

<table>
<thead>
<tr>
<th>Construction of filter strips</th>
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</thead>
<tbody>
<tr>
<td>The proposed method of construction (as yet untested) is to establish them before sowing, by running the seeding equipment along known contours, e.g. modified grade banks. Disperse crop seed only in the filter strip zone; sowing at the normal sowing rate.</td>
</tr>
<tr>
<td>Then when the whole paddock is sown in a downhill direction with a low slope, the seed in the filter strip is graded between the sowing rows; when points rather than discs are used.</td>
</tr>
<tr>
<td>Thus the filter strip zone should have about a double seeding rate and twice the number of stems/m² during the next summer when there is risk of erosive rains.</td>
</tr>
</tbody>
</table>
Figure 42. Mini−dams of detached stubble collecting in zones of concentrated flow through an area of attached stubble, which could happen when flows pass through a filter strip.

Paddock management guidelines for slowing overland flow rates are:

1. Minimise furrow slope by changing sowing direction on slopes > 2%.

2. Maintain good soil cover and surface roughness by keeping attached cover > 70% and use:
   a. Careful grazing management; perhaps rotational grazing.
   b. Careful decisions on cropping if there is a risk of a dry season.
   c. Minimal use of low cover crops in rotations, such as lupins and canola.
   d. Awareness of the risk of cover loss by termites on red loam soils in the NAR in no−till.
   e. Minimal stubble burning; consider chaff diversion to tramlines for better weed control in controlled traffic.

3. Consider testing ‘filter strips’ to capture detached stubble, slow flow rates and disperse concentrated flows.
D. Guidelines for diverting flows

Even with the best management practices for a farming system and the best of intentions, it will be difficult to avoid some overland flow and erosion risk on paddocks without some kind of earthworks to manage and divert excessive flows; especially when:

- Poorly controlled traffic and livestock trampling results in poor infiltration conditions.
- Poor seasons, unexpected grazing pressure and soil exposure soon after seeding results in very erodible surfaces.
- The landscape is already saturated from previous rain.

The form of earthworks which interferes less with cropping operations are broad–based banks. Some designs of broad–based banks are too steep to allow anything but cropping operations parallel to their direction. Broad–based roll–over banks allow the seeding, spraying and harvesting traffic to move over them without significant change of direction; though some operations may be more convenient than others.

A broad–based roll–over bank is a low profile earth structure, surveyed on a gradient, with a wide flat channel that enables farm operations (seeding, spraying and harvesting) to be carried out at right angles to the direction of the bank. The bank would discharge into a grassed waterway. The main features are minimal interference with long run, downhill Controlled Traffic farming and minimal loss of arable area.

Figure 43. The farm air seeder unit traversing the demonstration of a broad–based roll over bank at Buntine 2006.

There is currently very limited experience with broad–based roll–over banks in the NAR; but the experience from Queensland and northern NSW has provided a framework for design of broad–based roll–over banks in the NAR.

The 'Downhill' project has been able to establish two demonstration broad–based roll–over banks (BBROB) in the NAR and from the experience of the growers who helped build the banks at Buntine (Figure 43) and Pindar can offer some preliminary information for their use; however much more testing, evaluation and demonstration is required.

I. Installation of trial broad–based roll–over banks

Using design criteria originally developed in Queensland – the first trial at Buntine involved the modification of an existing broad–based grade bank to form a broad–based roll–over bank, and the second at Pindar was a new structure. The broad–based bank has a channel increased to between 4–5 m compared to a conventional grade bank with a channel width of 1–2 m (Figure 44). The bank construction straddles about 20 to 25 m but now the whole bank area can be sown to crop.
Issues arising from cropping operations over the broad based bank in the 2006 winter growing season were:

1. Poor depth of seeding control on the crest of the bank, despite some capacity of the seeder to follow ground contours (DBS design).
2. Poor crop growth on the crest of the bank, probably due to poor crop nutrition in the ‘sour’ soil exposed from the centre of the original bank.
3. Difficulty traversing the bank with the spraying equipment (‘whip’ at the ends of the spray boom); it would be even more difficult at approach angles other than 90°, despite slowing down.
4. Impracticality of harvesting the crop parallel to the direction of sowing; harvesting was done parallel to the bank alignment.
5. Further understanding of the effects different crop residue levels and row directions can make on water flow and design parameters.

These issues have especially highlighted the need for more machinery design and development work.

The use of low cost ‘lowered’ banks
Some growers in the region chose to not fill in and level their surface water control structures when they adopted controlled traffic. Instead they were modified sufficiently to allow transit of cropping machinery (see Figures 45 and 46). There were still problems with some cropping operations, and the earthworks have proved inadequate for run-off control in some circumstances. However the modified banks still achieved the convenience of using C.T. more easily.

Paddock management guidelines for diverting overland flow are:

1. Consider modifying existing grade banks to allow traverse by cropping machinery. This option is relatively low cost—may help to protect bare soil exposed by modified earthworks and redirect run-off.

2. Consider installing well designed broad-based roll-over banks and suitable disposal zones for diverted flows.
Guidelines list for quick reference (with page index)

The summary guidelines below have been grouped to identify the main element discussed (underlined).

**Traffic and tillage management guidelines**
for improving and maintaining *soil structure* to maximise infiltration and minimise run-off—(p. 20).

**Grazing management guidelines**
for improving and maintaining *soil structure* to maximise infiltration and minimise run-off—(p. 21).

**Soil macropore and organic matter management guidelines**
for improving and maintaining *soil structure* to maximise infiltration and minimise run-off—(p. 21).

**Grazing management guidelines**
for improving and maintaining *soil cover* to maximise infiltration and minimise run-off—(p. 21).

**Crop residue management guidelines**
for improving and maintaining *soil cover* to maximise infiltration in controlled traffic and minimise run-off—(p. 22).

**Sowing direction and livestock management guidelines**
for maintaining *flow separation* of run-off—(p. 29).

**Paddock layout guidelines**
for minimising run-on—(p. 31).
for minimising *problems of low permeability areas*—(p. 32).

**Paddock management guidelines**
for slowing overland flow—(p. 34).
for diverting overland flow—(p. 37).

We hope this manual will be helpful to land managers by offering some technical options to reduce the risk of damaging overland flow and erosion when controlled traffic is applied in a downhill system over long slopes of less than 2.5% in the Northern Agricultural Region.
Summary of observations made over 3 years at the project monitoring sites and linked to potential risk and the main drivers/features that modify the risk level

Table 1. The following table is from Whale et al. 2007

<table>
<thead>
<tr>
<th>Case study</th>
<th>Observation from rainfall simulation</th>
<th>Support for general concept</th>
<th>Erosion/ run-off risk</th>
<th>Observation over 3 years</th>
<th>Key features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sermon Rd Downhill</td>
<td>Less run-off between tramlines with good cover.</td>
<td>NT + C.T. + no stock—low need for banks on slopes &lt; 2%</td>
<td>Safe</td>
<td>Some run-off esp. on tramlines</td>
<td>Good traffic control. No grazing/stubble retention promotes infiltration—furrows stay intact for flow separation.</td>
</tr>
<tr>
<td>Sermon Rd Ariel paddock across slope</td>
<td>Flow concentration at low points.</td>
<td>Cover in inter row</td>
<td>High risk in intense storms</td>
<td>Cascade down slope to form rills—gullying at main convergence</td>
<td>Furrows overflow at convergence points—upland run-on areas with high shedding capability.</td>
</tr>
<tr>
<td>Riverside</td>
<td>Stubble loss from wind—drought. Levelling of ridges—still more infiltration between tramlines.</td>
<td>NT+C.T. + no stock. Root mass in furrow—still good infiltration rate. Upland area slope &gt; 4%</td>
<td>Low on slope &lt; 2% Moderate to high—on upland</td>
<td>Cover loss from dry season and wind—ridges flattened—storm caused overland flow and top-soil removal</td>
<td>Good traffic control. No grazing/stubble retention—bank needed to reduce flow velocity from upland area.</td>
</tr>
<tr>
<td>Pindar</td>
<td>More run-off in areas with wide row spacing.</td>
<td>NT+C.T. + no stock.</td>
<td>Low on slope &lt; 2% Moderate to high on upland</td>
<td>Stable</td>
<td>Good traffic control. No grazing (stubble retention)—bank needed to reduce flow velocity from upland area.</td>
</tr>
<tr>
<td>Mallee Station</td>
<td>No cover. No defined furrow/ridges—low infiltration rate.</td>
<td>Heavy grazing (set stocked) and soil loosening</td>
<td>High risk in current condition</td>
<td>Unstable Surface loose</td>
<td>Grazing regime needs serious review. Consistent traffic control areas needed.</td>
</tr>
<tr>
<td>Buntine</td>
<td>Ripped sandy soil—good infiltration.</td>
<td>NT+C.T. Managed grazing</td>
<td>Low</td>
<td>Stable</td>
<td>Consistent traffic control areas needed.</td>
</tr>
</tbody>
</table>
References


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