Roaded catchments to improve reliability of farm dams

David Stanton
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Need for improved farm water catchments

Maintaining reliable on-farm water supplies is an on-going challenge for landholders throughout Western Australia. Improving reliability of dams by constructing a roaded catchment is one of the most cost-effective methods of improving the performance and reliability of a farm water supply.

A roaded catchment is a water-harvesting structure designed to increase the amount of run-off from the catchment above a dam (see Figure 1). The ‘roads’ of a roaded catchment are parallel ridges of earth with batters (or side slopes) that cause run-off to be directed into troughs or channels. The surface is lined with clay and compacted to make it smooth and impervious to reduce infiltration and increase run-off.

Figure 1: A typical farm dam with roaded catchment on an area of gently sloping land above the dam.
Winter rainfall is often of low intensity, and falls of less than 10 millimetres per day are common as shown for Goomalling in Figure 2. It often takes continuous rain of up to 50 mm to cause natural catchments to run water into farm dams. Therefore, building a roaded catchment to run water after only 8 to 10 mm of rainfall greatly improves the catchment efficiency.

The agricultural areas of WA have been drier than normal over the last 10 years and forecasters are suggesting that we will have more dry seasons. This will increase the need for improved catchments to improve the reliability of farm dams.

To work efficiently, good design and careful construction, followed by regular maintenance of roadded catchments, are very important. This booklet explains their use and specifications for Western Australian conditions, particularly the dryland agricultural areas of the South West.
Site selection

Site characteristics

The area chosen for the roaded catchment should have the following characteristics:

- clay, clay loam or sandy clay loam soil located close to the surface (< 60 cm);
- sited upslope and preferably within 500 m of the receiving dam (a longer collecting channel is likely to lose some water from low intensity rainfall events between the catchment and dam);
- ground slope of less than 5 per cent (steeper slopes require half-roads instead);
- free of major obstacles such as rock outcrops, trees and shelterbelts and
- avoiding areas of sodic or self-mulching soils.

Soil type

Roaded catchments are easily constructed where there are duplex soils with light topsoil and heavy textured clay subsoil within 20 to 60 cm of the surface. Good quality ‘dam-sinking’ clay is preferable. Medium-textured soils are also suitable if they are compacted with a roller to provide a hard, smooth and impermeable surface to the catchment.

Subsoils need to have a low shrink-swell factor and contain at least 35 per cent clay. Some indication on the likely shrink-swell characteristics can be gained by hand texturing the soil and allowing it to dry. Very plastic soils will shrink and crack as they dry out. These soils require more rainfall to generate run-off from the catchment and should be avoided.

Many soils in agricultural areas have a sandy or loamy sand surface (often containing ironstone gravel) above a clay subsoil. These soils are normally satisfactory for roaded catchments if the depth to the clay is less than 60 cm. If the clay material to be used to cover the roads is deeper, then complete removal of the unsuitable sand or gravel overburden is recommended. In these cases, it may be more economic to use other water harvesting techniques such as a flat batter dam, or chemical treatments capable of reducing the permeability of the surface and reduces high cost of removing the overburden.
To provide a suitable soil for roaded catchment construction where surface sand and gravel soils contain very little clay (as in parts of the Esperance sandplain, the south coast east of Albany, and the West Midlands), the surface will need to be covered with a blanket of clay or the topsoil removed.

Soils unsuitable for ‘roading’ are clays that crack, crumble or become friable on drying, and coarse gravel or loose sand that has no clay base. Strongly structured soils such as self-mulching clays are unsuitable because of low run-off. Areas of crab-holes or gilgai should also be avoided due to the swelling and shrinking properties of the clay.

**How roaded catchments work**

Roaded catchments increase run-off by:
- increasing the slope of the surface;
- decreasing surface detention; and
- reducing the permeability of that sloping surface.

This is achieved by changing the form and texture of the soil surface to parallel ridges (roads) and channels (troughs), and blanketing these with a compacted clay layer. A grade or slope on the road channel allows the run-off to flow into a collecting channel, or directly into a farm dam.

A roaded catchment that conforms to recognised design criteria, and has been correctly surveyed will increase its capacity to run water from low intensity rainfall events, once the road surface has wetted up to a threshold value. The threshold is defined as the amount of rainfall needed before run-off commences. For example, roof areas have a threshold of less than 2 mm of rainfall; bitumen roads also begin shedding after 2 mm; and farmland can often require 25 mm before run-off occurs. A threshold value of 8 to 10 mm is achievable on most wheatbelt roaded catchments.

### Table 1. Selected rainfall events for a water supply east of York

<table>
<thead>
<tr>
<th>Date in July</th>
<th>Rainfall (mm)</th>
<th>Rainfall above 4 mm threshold</th>
<th>Daily flow into dam (m³)</th>
<th>Run-off (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>6.2</td>
<td>2.2</td>
<td>32</td>
<td>35</td>
</tr>
<tr>
<td>17</td>
<td>15.2</td>
<td>11.2</td>
<td>162</td>
<td>73</td>
</tr>
<tr>
<td>21</td>
<td>8.7</td>
<td>4.7</td>
<td>68</td>
<td>54</td>
</tr>
</tbody>
</table>

The Department of Agriculture has investigated the performance of roaded catchments since the late 1960s. Results from a property east of York are shown in Table 1 for a catchment with a 4 mm threshold.
Planning for reliable water supplies

To develop a reliable water supply the area of roaded catchment required depends on:

- rainfall and evaporation patterns of the district;
- quality of materials and condition of the catchment surface;
- size, depth and water-holding capability of the dam;
- number and condition of the livestock to be watered; and
- any additional demands placed on the water supply (e.g. pumping for domestic use).

Site investigation

Before designing and constructing a roaded catchment, a thorough site investigation and survey should be carried out. The extent of the site for the roaded catchment should be surveyed accurately and pegged out. The lower limit of the roaded catchment is determined by the provision of a safe receiving area or waterway above the farm dam.

The soil above the dam needs to be assessed to determine its suitability for roaded catchment construction. To do this, auger holes should be put down to a depth of at least 1 m and the different soil assessed in terms of water-holding capability. Samples need to be hand-textured to give an indication of soil strength. Soils with higher strength maintain their compacted shape and will not collapse after becoming saturated.

A reasonable idea of depth to clay can be obtained by digging or augering three holes per hectare, then using a soil probe to check the depth more frequently on the chosen site. The average depth to clay should be used in working out the design. Areas with shallow topsoil are more cost effective as road widths can be reduced.

Sediment trap

The surface of the roaded catchment, particularly if unfenced, will accumulate sediment composed of plant and animal residues plus soil erosion material. Sedimentation reduces the effective depth and storage life of the dam, decreases its reliability and increases maintenance costs of the roaded catchment.
Where sedimentation is unavoidable, a sediment trap should be constructed in front of the dam. The collecting channels should discharge into the sediment trap, which can be cleaned out easily.

Sediment in the water may also be removed by channeling it through a vegetative strip or apron before it enters the dam. The vegetative strip could be grass or more substantial plants such as rushes or reeds.

**Spillways**

Spillways, like waterways, need to be designed, surveyed and constructed correctly so that overflow from a farm dam does not damage the dam itself or the farmland below. Grassed spillways need to be designed to manage the run-off from at least a 1:20-year rainfall event. If the dam is in a drainage line, it will be necessary to have an emergency spillway on the other side to manage larger flows. Other situations where the dam will require an emergency spillway are:

- when the roooled catchment exceeds 5 hectares;
- where roooled catchment has been used to make a small farm dam more reliable and it is likely to overflow; or
- if the dam is located above farm buildings or shire roads.

Spillways need to manage overflow during wet winters and large run-off events following heavy rains after summer thunderstorms. They are used to convey the overflow to a safe disposal area and reduce the likelihood of damage to the dam, downstream infrastructure or cause erosion downstream.

**Fencing**

Roooled catchments should be fenced to exclude all livestock. Sheep and cattle can damage the catchment surfaces and manure will pollute run-off (and stored water in the dam) and promote weed growth.

**Advice**

For best results, consult an experienced professional for assistance with roooled catchment design. Poor design can be costly to correct and result in higher maintenance costs. Most importantly, it will affect the reliability and quality of the farm water supply.
Layout of roaded catchments

The layout of a roaded catchment varies with the landscape and depends on the slope of the land, the distribution of suitable soils and the required size of the roaded catchment. Depending on the slope of the ground surface, individual roads may be set out in various layouts to achieve the correct grades.

There are three basic layouts:

1. On gently sloping ground with slopes of less than 1.25 per cent (1:80), where the slope is close to that of the design grades of the road channels (see Figure 4).

   The roads are constructed straight up the slope in front of the dam and discharge directly into the front of the dam via a sediment trap. If there are many roads, a collecting channel can be built (see Figure 4).
2. On gentle to moderately sloping ground with slopes from 1.25 per cent (1:80) to 3.5 per cent (1:30) and where no stable waterway exists.

The roads are constructed obliquely across the slope and discharge into a collecting channel running in the opposite direction, as shown in Figure 5. The collecting channel directs run-off to the front of the dam.

3. On moderate to steeply sloping ground with slopes greater than 1:80 and where a stable waterway exists.
Roads are constructed across the slope and empty into a grassed waterway leading to the dam, as shown in Figure 6. For slopes steeper than 3.5% (1:30), a grassed waterway must be used because a collecting channel of the required grade would meet road channels at an angle too acute to be built conveniently.
Design characteristics

In designing a roaded catchment, the aim is to achieve:

- maximum water-shedding ability of the roaded clay surface; and
- minimum erosion or soil removal from the catchment surface.

Material and dimensions

The design must consider the relationship between the depth of the suitable soil material in determining the dimensions crest to trough of the roaded catchment. Where suitable soil material, that is with a high enough clay content, occurs at or close to the surface, road widths and the depth of cut depend on the desired camber of the batters of the roads. On these sites it is essential to bury the topsoil during construction, as there are advantages to the landholder. These include easier weed control and lower maintenance costs.

On sites where unsuitable sand or gravelly sandy soil overlies clay subsoil, the surface must be covered with the clay. A full cover can only be achieved if the depth of cut and road width allow sufficient subsoil to be excavated and if the construction method allows accurate placement.

On sites where unsuitable sand or gravelly sandy soil overlies clay subsoil, the surface must be covered with the clay. A full cover can only be achieved if the depth of cut and road width allow sufficient subsoil to be excavated and if the construction method allows accurate placement. It is essential on many sandplain soils (sand or gravel over clay) that the topsoil is fully covered during construction. Roaded catchments built on deep sand require a mantle of clay. This may need to be transported from other locations, and needs to be thick enough to carry out effective maintenance. The recommended mantle thickness of clay is 75 to 150 plus mm. The design and layout of the roads, need to provide low slope batters to ensure that the clay mantle covering the batter has a consistent depth.

Batters

The batters or side slopes of the individual roads are usually at gradients between 1:5 and 1:6. Road batters around 1:6 or flatter are more stable, effective and easier to construct and maintain, and provide a road surface that is clean and smooth.
Side slopes steeper than 1:5 have been used, but soil erosion is greater and construction is more difficult because of the instability of road rollers.

**Grades for collecting channels and roads**

Grades for the collecting channels and channels between the roads need adequate slope to allow water to reach the dam without soaking in or causing erosion.

The grade will depend on the erosivity of the available clay and the length of the roads. On soils that are likely to erode, the grades should be decreased. Channels with very shallow grades (less than 1:280) are difficult to make without ponding. (Ponding results from an uneven grade along the channel.) Roads larger than the maximum levels shown in Table 2 could erode even at the minimum gradient of 1:200.

The grade of the road trough or channel must be progressively reduced over its length so that the maximum slope occurs where the water flow is shallowest and the minimum slope is where the depth of water is greatest. The maximum fall allowable is 1:60 for up to 20 m, 1:100 for up to 100 m, and 1:200 at 500 m for catchments with a crest width of 8 to 20 m.

The grade at any point on a road depends on the contributing area above it. Table 2 shows suggested maximum grades at various distances from the upstream end of the catchment for three road widths. These grades should cause little erosion on most soils provided they have been well compacted.

Water in collecting channels runs deeper and faster than on side slopes so the grades must be much shallower to avoid erosion. Collecting channels which may carry large volumes of water must have grades less than 1:250. If this grade is exceeded, the collecting channel may erode. Where the collecting channel has eroded because of excessive grade, it can be stabilised with stone, concrete or bitumen.

The collecting channel that picks up run-off from individual roads and directs it into the dam is designed to carry the greatest quantities of water. It must have broad flat channels and be surveyed on the lowest grade of all, for example 1:280 and not exceed 1:250 (0.4 per cent) or 1:200 (0.5 per cent) depending on the soil type.

**Table 2. Suggested maximum grades at various distances from the upstream end of catchment for three road widths**

<table>
<thead>
<tr>
<th>Distance from top end</th>
<th>Crest-to-crest road width of catchment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8 -10 m</td>
</tr>
<tr>
<td>0 to 20 m</td>
<td>1:60</td>
</tr>
<tr>
<td>20 to 50 m</td>
<td>1:80</td>
</tr>
<tr>
<td>50 to 100 m</td>
<td>1:100</td>
</tr>
<tr>
<td>100 to 200 m</td>
<td>1:150</td>
</tr>
<tr>
<td>200 to 500 m</td>
<td>1:200</td>
</tr>
</tbody>
</table>
Other specifications

The depth of the channels is determined from batter slope (camber), width of roads, thickness of clay cover and depth of topsoil. These are all inter-related in the design of a roaded catchment. Roads must be wide enough and cut deep enough into clay subsoil to provide complete clay cover for the surfaces of the roads (see Figure 7).

Two principal factors that influence the design of a roaded catchment are:

- depth of overburden (i.e. depth down to clay);
- camber or steepness of batter (or side slope).

The depth of overburden and camber of the batters (side slopes) of the roads are worked out before construction begins. Depth of overburden is found by augering the site at several places. The camber of the batters is determined by soil type and capability of machinery. For a road grader, efficiency drops off when the camber is steeper than 1:5.

For any road, there is a certain minimum thickness of clay cover required on the batters to ensure good water-shedding ability over its whole area. At less than the minimum thickness, some of the rainfall is lost through infiltration (i.e. raised threshold).

For a given depth of overburden and batter camber the excavated depth of the road trough can be calculated to provide adequate clay cover. This calculation will provide a design width, crest to crest for the roads.

The relationship between depth of channel and thickness of topsoil for a clay cover of 75 mm is shown in Figure 8.
Figure 8 shows the relationship between the depth of topsoil and road width to provide 75 mm of clay cover for two batters or side slopes.

The required depth of cut and road widths can be read from Figures 6 and 7 for any depth to clay. The design dimensions are provided for an average clay cover of either 75 or 150 mm, although in practice the clay thickness will vary from point to point.

Roads can be 10 to 20 m wide from crest-to-crest, depending on the depth to the clay subsoil, and from 100 to 500 m long. A collecting channel more than 500 m long is less efficient and likely to lose water en-route from the catchment to the dam.

Channels should be **parabolic in cross-section** and of sufficient capacity to handle large volumes of water safely.

Several roads are usually required. Roaded catchments with a greater distance between roads are constructed more easily and require less maintenance as a deeper clay cover can be achieved.
Construction

Surveying the roads

The lower limit of the catchment is defined by surveying the lowest collecting channel that can safely deliver water to the dam. The grades for different parts of the road can be determined from Table 2 and the line of the first road surveyed and pegged. The next road is then pegged at the required distance from the first. The grade of this second road is checked, and if it is within the required limits, the process is repeated until the required area of catchment has been pegged.

If any road pegged after the first is outside the limit of grade, a new alignment at the correct grade is surveyed several road widths from the last satisfactory road. Intervening roads are then made parallel to this survey. The layout should be adjusted to minimise areas that are not used for roading.

Particular attention should be given to the survey at the discharge end of each road to avoid ponding. If channels are to discharge onto undisturbed ground, the end of each channel should be turned downslope to compensate for the depth of cut going from, for example, 0.3 m to zero at the discharge point at ground level. In this way, a continuous gradient can be achieved.

If the water discharges into a grassed waterway, no collecting channel is cut, but the bottom of the U-shaped channels should gradually be tapered up to ground level. Avoid ripping up the pasture cover on the grassed waterway.

Alternatively, if road channels are to discharge into a collecting channel of similar depth of cut, no adjustment to the survey will be required.

To prevent ponding of water at the outlet to the dam, or stored water from the dam extending over the catchment surface, road channels should not be cut below the full level of the dam (see Figure 4).

Collecting channel

If a collecting channel is used, it is pegged before construction, and roads are cut through its line to full depth. When all the roads are complete, the collecting channel is re-surveyed to connect the floors of each road channel at a grade of 1:200 or less. Once the roads have been completed, the collecting channel should be constructed with a fall of 1:200 towards the dam. The bottom of the channel should be cut to the depth of the U-shaped channels between the roads, but no deeper.
The level of the road channels and collecting channel must join precisely to allow a smooth transition between them. If the collecting channel is too low, there is a step-down and the road channel will erode, cutting back up the channel and resulting in the deposit of sediment in both the collecting channel and the dam. If the collecting channel is too high, there is a step-up, and water will pond behind the step and bank up back on the catchment. Ponded water will evaporate and fail to reach the dam, reducing the efficiency of the catchment.

The floor of the collecting channel should have a slight fall to one side, ideally with a slope of 1:10 or 1:20. This allows low flows to concentrate into a narrow channel at one side and minimise water losses. The side slope is such that the depth and velocity of large flows will not cause erosion.

The downhill face of the collecting channel should be covered with clay and rolled to provide an additional shedding surface.

**Construction equipment**

The preferred machine for construction is a large road grader. A bulldozer or scraper can be used to remove the overburden if the depth to clay is more than 60 cm. In some cases, it may be advisable to build a scraped catchment or spread front above the dam. Construction depends on the design and will differ between sites that require a clay blanket and those that do not. The first roads are built on the pegged base lines and others are built on either side of the base lines.
Removing overburden

The initial passes of the road grader move the topsoil into a windrow to commence forming the crest of the road. Clay subsoil should be exposed on either side of this windrow. The topsoil windrow should be rolled to compact it before proceeding.

The grader is used to push the topsoil from the centre (trough) to the outside (crest) of the road (well beyond halfway to the ridge crests). If the topsoil is not moved far enough, the overburden will show through in a line at about ground level enabling weeds to grow. Weeds reduce catchment efficiency and create a maintenance problem.

This process is continued until a width of clay has been exposed on either side of the road centre. This width needs to be a little larger than half the road width, which ensures that the overburden is pushed well aside and that when clay starts to be moved up the camber there will be a minimum of mixing. Thus for a road width of 12 m, part-way through construction there will be a width of about 8 m of exposed clay in its centre. The overburden is then compacted with a roller.

Claying up

The next step is the ripping up of the exposed subsoil clay in floors and grading it up the camber of the roads to completely cover the mound of topsoil on either side of the road centre. The clay is spread in successive layers on the side slopes. Each layer is then rolled. Grading is continued until the design depth has been reached.

This ripping and movement of clay up the camber of the roads continues until the calculated trough depth is reached. At this point, the road channel should be a smooth concave shape and the side slopes covered with a minimum of 75 to 150 mm of clay.

Compaction

The roaded catchment must be rolled to provide a smooth compacted surface that will work effectively. This lowers the threshold at which the catchment will generate run-off and enhances its durability.

If the surface is not compacted sufficiently, it will trap run-off in small depressions, erosion will result, and greater catchment area will be needed to fill the dam.
Because grader hire is usually five to six times more expensive than roller hire, omission of the roller wastes more time and money than it saves.

Multi-wheeled, rubber-tyred rollers are best as they can compact bumpy or broken surfaces and are useful over a wide range of soil moisture. Steel road rollers tend to produce very smooth surfaces, although there may be little compaction of soil between 'high spots' and moist soil can stick to the roller. Farm tractors can be used for compaction but are not as good as machinery designed specifically for the job. Rolling should be done when the overburden is being stockpiled and when the clay cover is being added to the cambers.

Compaction aims to provide a smooth, dense surface and it is vital to compact the clay cover by rolling it when moist. The soil must contain sufficient moisture to allow moulding and smoothing of the surface and give adequate support and good traction for the machinery. A soil that can be cultivated to a good tilth contains sufficient moisture for effective compaction.

In winter, wet conditions often limit the operation of wheeled machinery, while in summer, watering equipment is not readily available and the soil is normally too dry. For this reason, construction and compaction of roaded catchments is frequently limited to spring and autumn when soil moisture is close to the optimum.

**Maintenance**

To maintain the reliability of the water supply, roaded catchments need regular maintenance. When the threshold increases, run-off is reduced and fewer rainfall events generate run-off. An increase in threshold above the intended design reduces reliability of the water supply, and in below-average rainfall years, this can be critical.

A well constructed roaded catchment that has correctly designed gradients on the roads and a compacted, stable surface of clay that does not readily support plant growth requires little maintenance during the first few years. Eventually, weeds will invade the catchment and sand and silt will accumulate in the troughs and then maintenance is required.
When recommended grades and dimensions are used to construct a roaded catchment, soil erosion is seldom a major problem. Where clays are prone to dispersion, the dimensions will need to be altered to control the water erosion.

Rooded catchments need maintenance or reconstruction to:

- restore the catchment surface and maintain efficiency;
- control soil erosion; and
- control weed growth.

**Restoring the catchment surface**

The accumulation of sediment on the surface of the catchment will increase its threshold, increasing the amount of rainfall needed to cause run-off into the dam. The surface can be restored by removing accumulated sand and silt with a front-end loader. It is then re-worked with a road grader to restore the surface. Compaction using a roller improves its function, provided the material is not too dry.

**Soil erosion**

Water erosion, showing as rilling of the catchment batter or side slopes and gullying in the troughs and collecting channels, can occur if the catchment has not been designed correctly or built of unsuitable material.

If the clay cover is eroded away, more permeable material is exposed at the surface allowing weeds to grow. This raises the threshold and catchment efficiency is reduced. The eroded material is washed into the dam causing sedimentation and reducing its effective storage capacity.

When recommended grades and dimensions are used to construct a roaded catchment, soil erosion is seldom a major problem. Where clays are prone to dispersion, the dimensions will need to be altered to control the water erosion.

**Weed control**

Weeds growing on roaded catchments can dramatically reduce run-off from the surface by breaking up the compacted soil and thus increasing infiltration.

Weeds raise the catchment threshold by loosening the compacted surface and absorbing a small part of each shower of rain.
Most run-off occurs in winter so early control of winter-growing annual weeds is important. Any dry weed residue from the previous year should be burnt before the break of the season. Weeds can be controlled by scraping the surface with a road grader. Residual herbicides can contaminate the run-off water stored in farm dams and should not be used.

**Exclusion of livestock**

Livestock will damage the catchment surface affecting the threshold requiring more frequent maintenance. Animal residues (manure) encourage weed growth, cause bacterial and organic pollution of run-off and promote algal growth in dams. Roaded catchments should be fenced immediately after construction to exclude all livestock. The fencing should be regarded as permanent and planned to allow access and space for maintenance.

**Further reading**


Farm dams in Western Australia. Bulletin 4609. Department of Agriculture, Perth, WA.


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