

## Prescriptive measures for the prevention of road to stream linkage.

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**SUMMARY:** Unsealed roads are recognised as one of the dominant sources of sediment entering streams. Sedimentation of streams can affect stream morphology, water quality and aquatic biota, and considerable funding is directed to protection programs such as stream fencing, bank stabilisation and establishment or retention of buffer zones. Road sediment can circumvent these protective measures when drainage structures erode and form gullies which connect segments of road directly to the stream system. This paper reports on the extent of road to stream linkage in a 57 km<sup>2</sup> forested catchment in south east NSW. The contributing length of road segment and the gradient of the hillside at the discharge point is used to predict the occurrence of gullies at drain outlets. The relationship between contributing road length and discharge gradient is used to derive drain spacing tables, which can be constructed quickly and easily for each road network. The drain spacing tables can then be used to plan the location and drainage requirements of new roads as well as the rehabilitation of existing road networks.

### THE MAIN POINTS OF THIS PAPER:

- Sediment delivered from roads to streams affects channel morphology, water quality and aquatic biota.
- High volumes of runoff and sediment, generated by unsealed roads, are delivered directly to streams by gullied road drain outlets.
- These gullies, which are difficult to remediate once formed, negate or reduce the benefits of buffer strips and riparian zones.
- Specific road drainage guidelines, using contributing length and discharge gradient, can help prevent gullies at drain outlets.
- The guidelines are quick and easy to develop for any catchment and assist in reducing the persistent impacts of road to stream linkage.

## 1. INTRODUCTION

### 1.1. Background

It is estimated that over 10 million dollars are spent annually on riparian restoration projects to protect Australian river systems[0]. One of the primary functions of these features is to reduce sediment and nutrient flux in surface water before sediment enters the stream, although other important benefits are recognised (see Prosser, this volume). Given the extent of this financial investment, it is imperative that we understand conditions in which these features are likely to be made 'redundant' due to complete by-passing and/or poor placement within the catchment with respect to the major sediment and nutrient sources.

Channelised pathways or gullies that develop at road outlets may short-cut designated riparian or buffer strips, and deliver sediment straight streams. In some cases, significant gully erosion can increase the drainage network, affecting the extent of linkage between sediment source and the stream, and consequently sediment delivery from source to stream.

Conceptually, road to stream linkage can be perceived as expanding the existing natural channel network through the linkage of gullies and road segments to the streams. The table drains, which route road generated runoff from the surface of the road to the drain outlet,

and the gullies that link the drain outlets to streams function as first order channels. The major difference between linked road drains and natural channels is the supply of runoff and sediment available for transport, which is greater on roads than on undisturbed hillslopes drained by natural channels.

Roads are common across many land uses. Even in the most well-managed and environmentally sensitive areas, such as National Parks and protected forest areas where streams have high ecological value, degradation may occur through road to stream linkage. In this paper, we outline the extent of road to stream linkage using research data from a 57 km<sup>2</sup> catchment in south eastern NSW. The catchment has a roading network of about 84 km of various classes of roads, used primarily to extract harvested timber from logging areas. The roads resemble those found in any agricultural region and have no unique attributes that limit the applications of these findings to forestry environments. The only unique aspect of the study area is the Best Management Practice (BMP) system used to regulate roading and timber harvesting activities in State Forests. This is controlled as part of a Non-Point Source (NPS) Pollution Control Licence (PCL), administered by the NSW Environmental Protection Authority (EPA). As such, road networks in NSW State Forests are planned and better maintained than roads in other environments which are not managed within such a strict code of

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practice. Having identified the factors responsible for direct linkages between roads and streams, we present management options for the planning, prevention, and protection of streams from the effects of a road network.

### 1.2. The Problem

The importance of roads as a source of excess sediment and runoff is well supported in the literature (Reid and Dunne, 1984; Grayson *et al.*, 1993). Roads are highly compacted surfaces with low infiltration capacities, generating higher volumes of runoff than other, less compacted areas. In addition, roads generate runoff more quickly and during lower rainfall intensities than on undisturbed areas. More recently, the significance of gullies and other channelised pathways, as a mechanism for sediment transport from roads to streams has been recognised (Montgomery, 1994; Wemple *et al.*, 1996).

Gullies that occur at road drain outlets and link to a channel have several impacts on streams:

There is the initial increase in the supply of eroded material as the gully incises into the hillside and continues eroding towards a stream.

Once established, a gully provides a permanent pathway from the drain outlet to the stream.

Areas around gullies become susceptible to seepage-induced mass failures.

Gullies negate the protective benefits offered by buffer strips or stream-side vegetation.

### 1.3. Study Aims

There were two primary aims of the study:

To evaluate the extent of road to stream linkage in the Cuttagee Creek catchment, and,

To determine the physical characteristics of road drainage design and location that can explain road to stream linkage.

### 1.4. Study Site

The data presented in this paper were collected as part of a study investigating road to stream linkage in the Cuttagee Creek catchment, located approximately 7 km south of Bermagui in south east NSW (36°25"00S 150°05"00E) (Figure 1).

The catchment ranges in elevation from sea level to 364 m above sea level and is characterised by deeply incised drainage lines. The main channel of the catchment, Cuttagee Creek, is a fifth order, low gradient (~0.01 m/m) stream which shows little evidence of within channel storage, suggesting high delivery potential of road-generated sediment. The road density in the study area is around 2 km/km<sup>2</sup> and, the road surface occupies around 1% of the study area (Table 1).

Forest roads in Eden Management Area are generally permitted on hillslopes with gradients up to 30 degrees but the gradient of the road itself should not exceed 10 degrees[0]. Most roads (Class IV and V) are surfaced with locally derived coarse gravels and all roads are crowned (Figure 2).

Table 1: Characteristics of the road and drainage networks for the study area.

Feature	Study Area
Catchment Area (km <sup>2</sup> )	37.73
Stream Network Length (km)	164.99
Stream Network Density (km/km <sup>2</sup> )	4.37
Road Network Length (km)	75.23
Road Density (km/km <sup>2</sup> )	1.99
Road Network Area (km <sup>2</sup> )	0.40
Proportion of Catchment Area Routed (%)	1.06

There are three main types of drain used on the road network in the catchment: mitre drains, push-outs, and culverts (Figure 2). Mitre drains are extensions of the road table drain created by curving the table drain off the road alignment and onto the hillside. Push-out drains are created along low gradient ridges and in saddles and relieve water from the table drain. Culverts are used in conjunction with cut and fill roading to drain the cut batter side of the road, via cement piping, which discharges water onto the fill batter side of the road and then down hill.

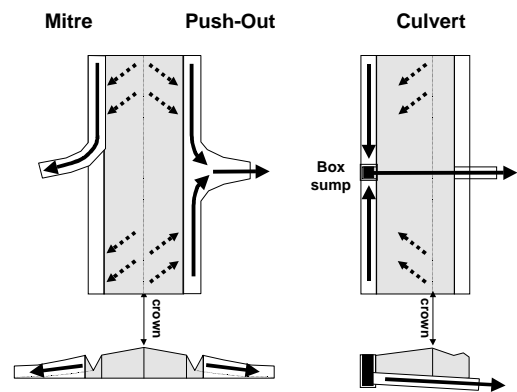


Figure 2: Plan and cross section schematic of mitre, push-out and culvert drain types. Shaded area represents the road surface and dashed arrows show direction of road runoff. Solid arrows show discharge from drain structure[0].

## 2. METHODS

The location of all road drainage structures within the study area (Figure 1) was recorded using a Differential Global Positioning System (DGPS). Drain locations were stored as a digital coverage on an ArcView Geographic Information System (GIS). By using these data with stereo-aerial photographs the location of all roads in the study area was established. Data on the position of road segments in relation to the natural drainage network, the age of road segments, road class, and location of different drain types were used as strata for selecting a representative sample of road drains and segments in the study area.

A detailed survey of the road surface, drain structure and linkage feature variables was then conducted on these selected road segments. Contributing length and width of road segments, batter heights, drain and gully lengths were measured to 0.1m with surveyors' tape. Road, drain, gully, and hillside gradients were recorded with a clinometer to the nearest degree by two

observers; if the two observations of gradient did not concur the average of the two values was recorded. In total, 171 metre drains, 23 culverts, 20 push out drains and 4 near stream cross-bank drainage structures were surveyed.

The interpretations of this survey form the basis of the results presented in this paper. The catchment is serviced by three types of engineered road (Table 2). Class V and VI roads would be the most common standard of road used by general traffic in Shires, National Parks and other forest areas.

Table 2: Functional description of road classes in the Cuttagee Creek catchment.

Road Type	Formation Width	Functional Description	Class
Primary Access	5.5 to 7.3m	All weather, 2 lane, sealed	III
Secondary Access (IV)	4.2 to 5.5m	All weather, unsealed, 1.5 lane	IV
Secondary Access (V)	4.2 to 5.5m	All weather or dry weather, loose surface, 1.5 lane	V
Feeder Access	3.7 to 4.2m	All weather, unsealed, 1 lane	VI
4WD or Fire Trail	~4m	4WD access only, used primarily for fire control and water access	VII

### 3. EXTENT OF ROAD TO STREAM LINKAGE

There are several degrees of road to stream linkage which determine the extent to which roads and streams are connected (Table 3). These linkage classes were assigned based on the observed geomorphological impact of the erosional features and the perceived sediment delivery potential of the pathways.

Table 3: Classification of road to stream linkage used to classify geomorphological features found at drain outlets during road drain survey (Mockler and Croke, in prep.).

Class	Linkage	Visible Geomorphological impact	Sediment Delivery
1	None	Channelised flow pathways or rills extend <10m from drain outlet.	Low
2	Partial	Discontinuous rills and gullies extending >10 m from drain outlet and terminating >10 m from stream	Low-Moderate
3	Gullied	Continuous rills and gullies extend from drain outlet into stream channel.	Moderate-High
4	Direct	Drains discharge directly into stream or road runoff flows directly into streams.	High

Around 44 %, or about 73 km, of stream network in the study area was affected by road to stream linkage (Figure 3), resulting in an increase in channel network extent of 6 % (Table 4).

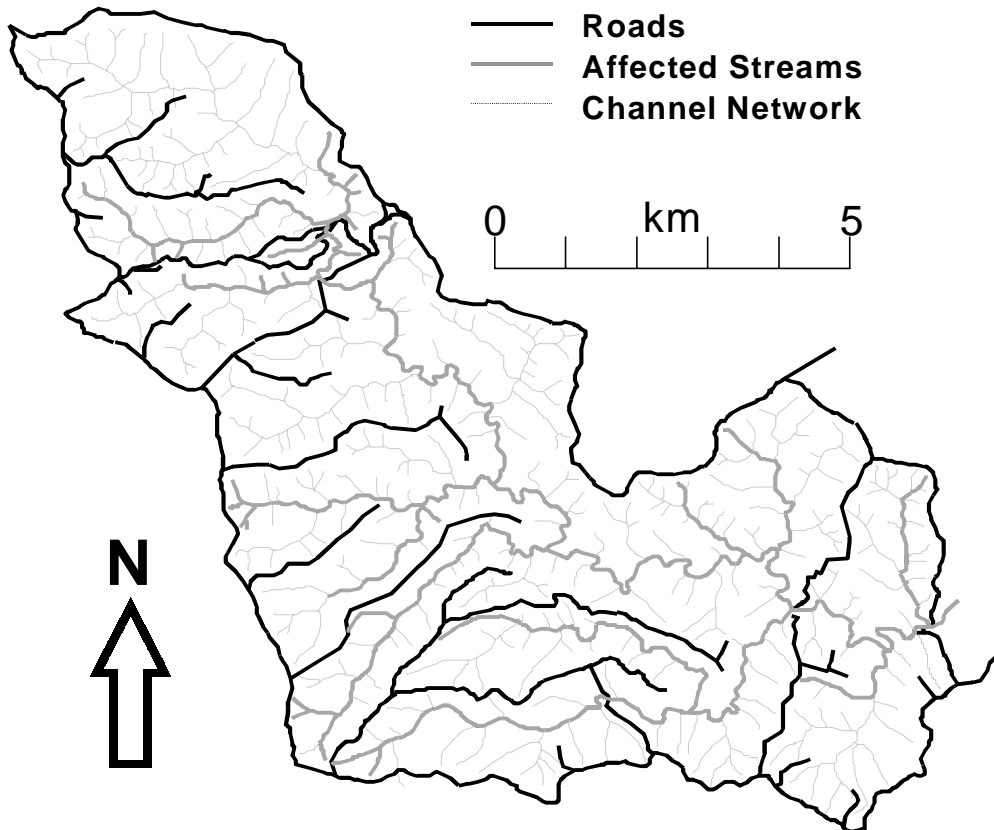


Figure 3: An example of the widespread spatial extent of streams affected by road to stream linkage in Cuttagee Creek catchment. The catchment boundary is not included as the predominantly ridge-top roads around the perimeter of the study area are generally aligned on the catchment divide.

Table 4: Calculated increases in drainage density by inclusion of linked road length segments and gully lengths by stepped inclusion of four classes of road to stream linkage (Mockler and Croke, in prep).

Linkage Type	None	Partial	Gullied	Direct
Road Lengths Linked (km)	0.00	0.67	5.21	0.27
Gully Lengths Linked (km)	0.00	0.43	3.37	0.03
Total Additional Length (km)	0.00	1.1	8.6	0.30
Observed Changes				
Total Drainage Length (km)	164.99	166.09	174.69	174.99
Drainage Density (km/km <sup>2</sup> )	4.37	4.40	4.62	4.63
<b>Increase in Drainage Density (%)</b>	<b>0.00</b>	<b>0.66</b>	<b>5.83</b>	<b>6.01</b>

Furthermore, the entire 14 km length of the main channel in the catchment is affected by sediment entering the streams through these pathways. This channel contains permanent water, including pools that are used by several fish species for breeding. Sediment entering the stream system will eventually be deposited in the estuarine Lake Cuttagee (Figure 1). In other catchments this could be a municipal reservoir used for water supply.

#### 4. FACTORS AFFECTING LINKAGE

The occurrence of gullies and rills at drain outlets is explained here by the relationship between two variables; the contributing area of the road surface generating runoff and the gradient of the hillside onto which the drain discharges.

##### 4.1. Contributing Area

Several components of a road or road network generate runoff. Ridge-top roads have no upslope contributing area and generate runoff on the road surfaces only, so that the length of road segment directly controls the volume of surface runoff generated. Logically, long segments of road will contribute higher volumes of runoff to a drain than a shorter segment of road. Roads that are cut into the hillside have much larger contributing areas, including runoff generated from the upslope hillside, the batter, and any subsurface flow the batter intercepts during a rainfall event.

##### 4.2. Gradient

The gradient of the hillside where a road drain discharges runoff affects the velocity and erosivity of the runoff. Current guidelines dictate that on NSW State Forest roads, it is the gradient of the road way that is used to regulate drainage spacing (Ryan, 1996).

##### 4.3. Erosion Threshold

Following the approach of Montgomery (1994), a threshold curve for these two variables, contributing area and hillside gradient, was found to discriminate between gullied and ungullied drain outlets in the study catchment. Gullied, or fully linked, drains plot above the curve and ungullied, or unlinked, generally plot below the threshold curve (Figure 4).

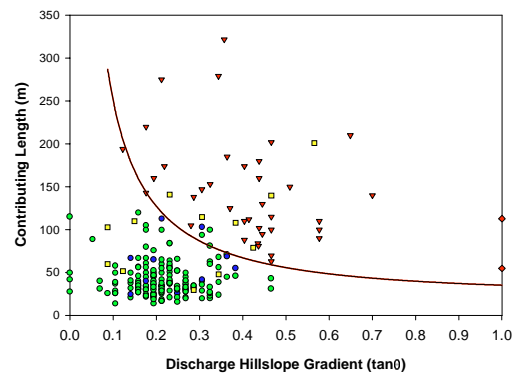


Figure 4: Plot of contributing length (m) versus discharge hillside gradient for surveyed sections of class IV, V and VI roads. Circles are ungullied, squares are partially gullied, and triangles are gullied drain outlets (Mockler and Croke, in prep).

The threshold curve in Figure 4 has the function:

$$L = \frac{25}{\sin \theta}$$

where:

L(m) is the maximum contributing length, 25 is the calculated coefficient for the threshold curve, and,  $\theta$  is the discharge hillside gradient in degrees. The use of contributing road area yields a slightly more distinct separation of linked from unlinked points, however contributing length used here as it simplifies the practical application of the threshold in a design table and consequent implementation by road managers in the field.

A similar relationship has been developed for road drainage outlets in the USA, suggesting that the relationship is relatively robust across environments (Montgomery, 1994). Differences in the occurrence of gully erosion between the different types of drains were found in the study area. Most culvert outlets (91 %) were found to have gullies because they drain water from longer segments of road, capture water from upslope contributing areas and discharge the runoff through pipes, which tend to focus the discharge into a single flow path. Only 7 % of mitre drains and 22 % of push-out drains were found to have gullied outlets. Discharge from a push-out or mitre drain tends to be spread out onto the hillside, as the outlets of these two drains are wider and lower in gradient than culvert pipes.

The threshold curve is used here to create a drain spacing table specific to the study catchment (Table 5). The threshold curve method of determining gully occurrence should be easy to apply to any individual catchment. Data need to be collected to derive a threshold curve for an individual catchment as road design, soil properties and climate, particularly rainfall, will affect the shape and position of the fitted curve in each catchment. Therefore, spacing guidelines for each catchment will vary in relation to contributing length and discharge gradient. By incorporating such a table into road plans new roads can be built with drain spacings that will reduce the occurrence of gullied drain outlets and reduce road to stream linkage.

		Drain Discharge Hillslope Gradient (degrees)							
		2.5	5.0	7.5	10.0	15.0	20.0	25.0	30.0
Roadway Gradient (degrees)	0	-	285	190	145	95	70	55	50
	1	200	200	190	145	95	70	55	50
	2	175	175	175	145	95	70	55	50
	3	150	150	150	145	95	70	55	50
	4	125	125	125	125	95	70	55	50
	5	100	100	100	100	95	70	55	50
	6	90	90	90	90	90	70	55	50
	7	80	80	80	80	80	70	55	50
	8	70	70	70	70	70	70	55	50
	9	65	65	65	65	65	65	55	50
	10	60	60	60	60	60	60	55	50
	11	55	55	55	55	55	55	55	50
	12	50	50	50	50	50	50	50	50
	13	45	45	45	45	45	45	45	45
	14	40	40	40	40	40	40	40	40
	15	40	40	40	40	40	40	40	40

Table 5: Proposed maximum drain spacing design table for Cuttagee Creek study area. Drain spacings are based on combined criteria of: (1) avoiding road surface erosion, based on Forest Code of Practice guidelines, and (2) avoiding gully erosion at drain outlets.

#### 4.4. Practical Implementation of the Erosion Threshold for Road Drain Spacing

To implement the erosion threshold curve into the road management guidelines of a catchment requires a survey of existing road sections and drain outlets, analysis of the data, derivation of the threshold relationship, and integration of the erosion threshold curve parameters with the existing road drain spacing guidelines.

After selecting representative road sections to be surveyed each drain would have details of contributing length and width of road discharging runoff through each drain. Road travelway gradient and the gradient of the hillside where the drain discharges also needs to be collected. These measurements can be made quickly using a surveyors' tape and clinometer. Alternatively, the use of a measuring wheel would greatly increase the speed of data collection on long sections of road.

Around 200 surveyed drainage structures would provide enough data for reliably fitting the threshold relationship but this value is dependant on the number of surveyed drains with eroded outlets. Once the curve has been fitted the coefficient of determination for the threshold equation can be used to produce a simple look-up table that determines the maximum drain spacing for a given discharge hillslope gradient for the area of interest. Combined with the existing guidelines for drain spacings, which are based upon avoidance of road surface and table drain degradation, maximum drain spacing distances can be determined.

With these look-up tables the drain spacings for new roads can be determined so that both the road surface and table drains do not erode and gully erosion does not occur at drain outlets. On existing road networks the simplest implementation of the look-up tables would be to increase the number of drains on sections of road where drains are currently spaced too far apart. Drains with established gullies could have new drains installed above the existing drain. The drain with erosion at the

outlet could then be sealed off and remediation of the gully initiated.

## 5. MANAGEMENT OPTIONS

This study improved our understanding of the factors that contribute to road to stream linkage and in so doing, allowed us to develop appropriate management options. As with all cases of gully erosion, prevention is the best option, as once formed gullies are difficult to remediate and their effects may be long lasting (Prosser and Soufi, 1998). Below we outline some practical solutions that may be considered in environments where road to stream linkage is an existing, or potential problem.

### 5.1. Planning

Clearly, the preferable option is to plan roads with respect to catchment terrain, to avoid areas of high risk, particularly stream crossings, on steep hillsides or on roads adjacent to streams and buffer zones. Suitable planning strategies are to:

- utilise ridge-top roading alignments, on these roads the distance between drain outlet and stream or buffer zone is maximised,
- avoid stream crossings where possible, and
- avoid road alignments where steep drain discharge gradients cannot be avoided.

### 5.2. Prevention

Current drain spacing guidelines used by NSW State Forests outline maximum separation of drains based on the gradient of the road travel way aimed at preventing on-road erosion. In order to prevent erosion at the drain outlet, the gradient of the hillslope where road drain runoff is discharged, appears more critical than the gradient of the road travel way. Road drain outlet gully erosion can be prevented by utilising a drain spacing table as part of the road construction and design procedure (Table 5).

### 5.3. Protection

- Three standard practices already exist for the protection of streams from roads which cross or pass close to streams.
- The use of spillway devices, particularly at culvert outlets, is recommended to prevent the development of plunge pools or scouring of the relatively unstable fill batters found below many culvert outlets.
- At stream fords, cross banks or roll over drains can be constructed a few metres above the stream bank-full level. This prevents vehicle wash from flowing straight back into the streams after a crossing.
- The use of constructed sediment traps at drain outlets should be used to capture sediment before it is delivered into the stream-side area.

## 6. CONCLUSIONS

- Gullies at road drain outlets can lead to high delivery of runoff from the surface of unsealed roads directly to streams.
- Road to stream linkage negates the benefits of buffer strips in reducing sediment/nutrient fluxes to streams.
- Drain spacing guidelines have been developed here to prevent erosion at drain outlets, thus avoiding one of the main delivery pathways for road-derived sediment in a catchment.
- Guidelines should be relatively easy to derive for any catchment, requiring the collection, for each road section, data on width and lengths and road and hillside gradients. Depending on the drain spacings and engineering standard of the road sections around 75 drains can be surveyed per day. Around 150 drains is an adequate sample size for fitting a threshold curve with the discrimination improving with the number of linked drain outlets observed.

## 7. ACKNOWLEDGEMENTS

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